Politechnika Slaska

FINAL PROJECT

“Study and design of the structure of a deposit of LGP with composite “

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1.INTRODUCTION

1.1 The main idea

Nowadays the engineers are improving their knowledge in composite structures. In this final project, we will make the study of a deposit of high pressure made it by composite. This kind of composition for manufacturing the deposits are unusual actually, but there is a lot of improvement in this topic.

At the first time, we make an study of the common deposits for different flammable liquids like LGP (Liquefied Gas Petroleum) o LGN (Liquefied Gas Natural).We realize that the most common materials for manufacturing this kind of deposits are the steel, alloyed with carbon or another materials, stainless steel, Copper and alloyed aluminum. So, the first step is to build a deposit that must pass the legal specifications of security and respect of the ambient medium. This is one of the most important points of the design, because we are building a deposit without a common material, so we have to take care about that every part of the design are secure and optimal.

The idea of design the deposit with composite, is for improve the designs with this kind of material, that are usually more light and resistant with the high stresses.

There is different kinds of deposit, but we are going to focus in one this types:

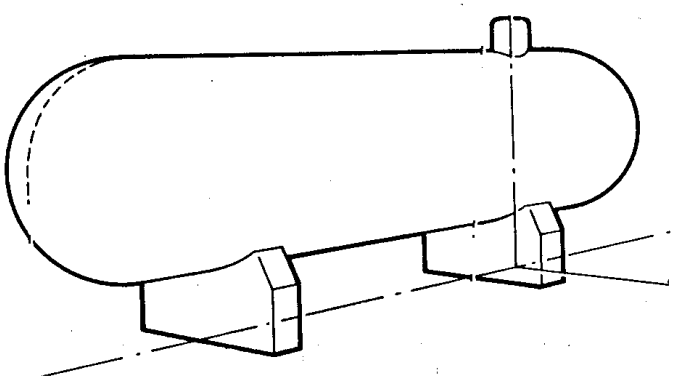
" Horizontal deposit with cylinder shape and with hemispherical caps"

There is different ways to use this deposits:

- To save high quantities of LGP/LGN in a light deposit for an emplacement without the cost of use high space for saving the liquid and the cost of maintenance, that in big deposits are always so much more higher.

- To save water in high pressure when we have to impulse the water to a higher place. In this case is common to save the water in the same pressure of the bombs that impulse the water, resolving with this the " Watter Hammer " and making easier the work of impulse the water.

One example of the idea is the deposit of Pic 1. Don't forget that our deposit will be made by composite.



1.1 Pic1: Example of the idea of the design of the deposit

1.2 Study of Objetives

The main objectives of the design, following the norm for the deposit of high pressure, are this:

- Liquid to save: LGP (Liquefied gas petroleum) or Water

- Service pressure: 21 bar

- Security design pressure: minimum 30% more than the service pressure

- Economic design of the deposit, taking in count materials, the cost of this, manufacture method, security systems, size of the deposit taking in count the emplacement .

- Size of the deposit taking in count that we are preparing a deposit of composite, so this can be more resistant than the common deposits and more light, we can push the design for build a deposit with more extreme conditions, but always respecting the security conditions and the norm of design.

- Optimal thickness. Minimum quantity of composite laminates.

- Security systems of the deposit taking in count the norm of the designs.

- Optimal conditions of design for the variations of the temperature, the pressure, the vibrations , and the seismic movements.

1.3 Changes in the main idea

At the first time, we thought that because we are designing a deposit of composite (we know that the properties of this kind of materials are so much more better than the materials individually), we can prepare a deposit of high size for save a high quantity of liquid and with high pressure.

The first idea was this kind of deposit:

- Longitude: 12 m

- Radio: 1.5 m

- Service pressure: 21 bar

- Design pressure: 30 bar

- Liquid to save: LGP (LIQUEFIED GAS PETROLEUM)

After the first study of this deposit, and talk with the one of the directors of the company ISOLUX CORSAN S.A. Madrid (Spain) about his opinion of the design of the composite deposit I realize that:

-The deposit would be bigger than the common necessary conditions for save this kind of liquids.

- The thickness would be too high, and this broke one of the objectives of the design, to have less thickness and more resistance than with the normal materials of design .

- That the size of the deposit would be too high for manufacturing it in a economic and optimal way, because there isn`t too much companies that manufacture this kind of big deposits in a real economic way.

- that following the norm and the common way of design, it is more economic and optimal to have 2 o 3 small deposits than a big deposit.

- The problem that with this dimension of composite it would be more expensive, so not rentable.

-That this pressure is not useful for saving this kind of liquids, so is better to reduce it a little bit.

After that, following the norm of design, I had to reduce the maximum service pressure and the dimensions of the deposit, and we finally choose:

- Length: 5m

- Radio: 0.5 m

- Service pressure: 21 bar

- Security design pressure: 30 bar

- Security coefficient: 3

- Thickness: (After the study) 2 cm

- Liquid to store: LGP (LIQUIFIED GAS PETROLEUM)

1.4 Physic and chemist characteristics of LPG

Using the reference [7], we know that LPG stands for liquefied petroleum gases propane and butane. Fuels are hydrocarbons which are in normal state in the gas phase and are stored in tanks in the liquid phase under high pressure.

The most common are the GLP commercial propane and butane. Both are sold in compliance with the current specifications (303 BOE.num 19/12/84 and 09/22/82 num.227 of). The most common mixtures ranging from 70/30 and 60/40 in ratio of propane / butane respectively.

Flammability and combustion: Form flammable mixtures with air, and need a lot of air for combustion. The flammable point of the LGP is between 400º and 450º and it is necessary to have up to 15% of air in the mix for produce the combustion.

Corrosion: The LGP not corrode steel or copper or its alloys. Synthetic rubbers not dissolve so that these materials can be used to build facilities. If you dissolve fats and natural rubber.

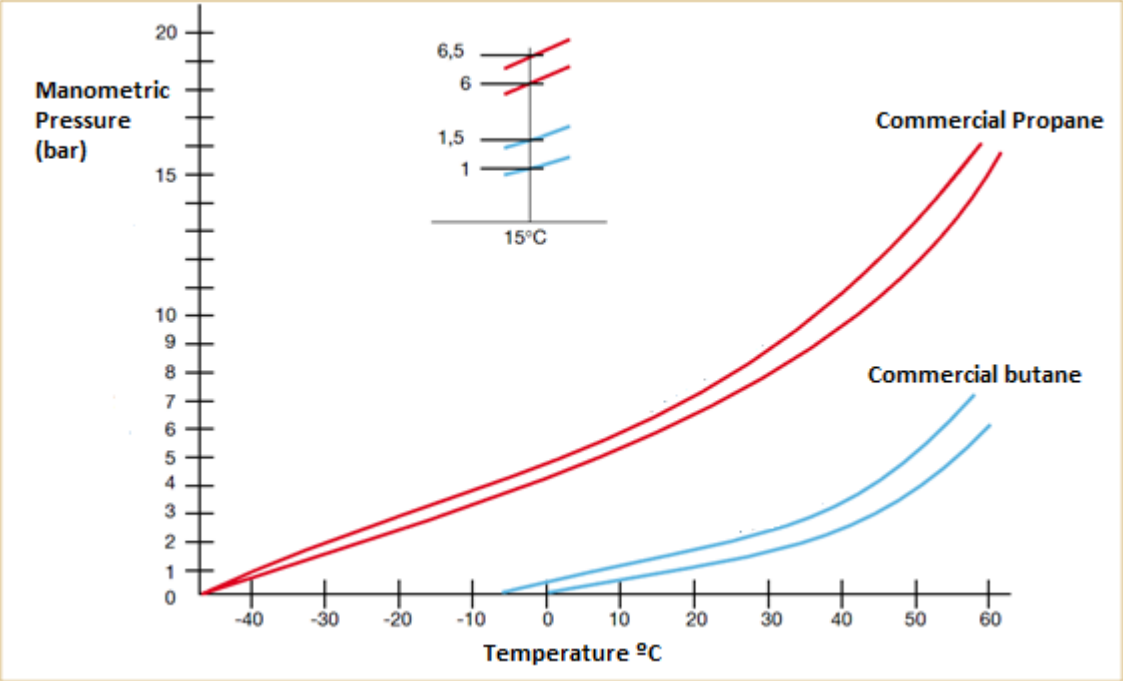
Toxicity: The LPG is not toxic.

Odor: lack of color and natural smell. To detect leaks by smell, an odorant is added based quirky mercaptans, which feels much before the mixture reaches the lower flammable limit.

Pollution: It's a green fuel, its combustion does not pollute the atmosphere, produces no odor or residue. The LGP not dissolve in water or pollute.

Filling ratio: The LGP in liquid phase dilate by temperature more than the containers containing them, so these are not fully filled for absorbing the expansions. The maximum filling level regulation is established at 85% by volume considering the mass at 20 °C ,leaving the remaining 15% to the gas phase.

The gas pressure inside a container is approximately 8 bar to 2 bar for propane and butane. To a maximum working temperature of 60 ° C the respective pressures are 21 bar and 7.5 bar (Reference [7]..



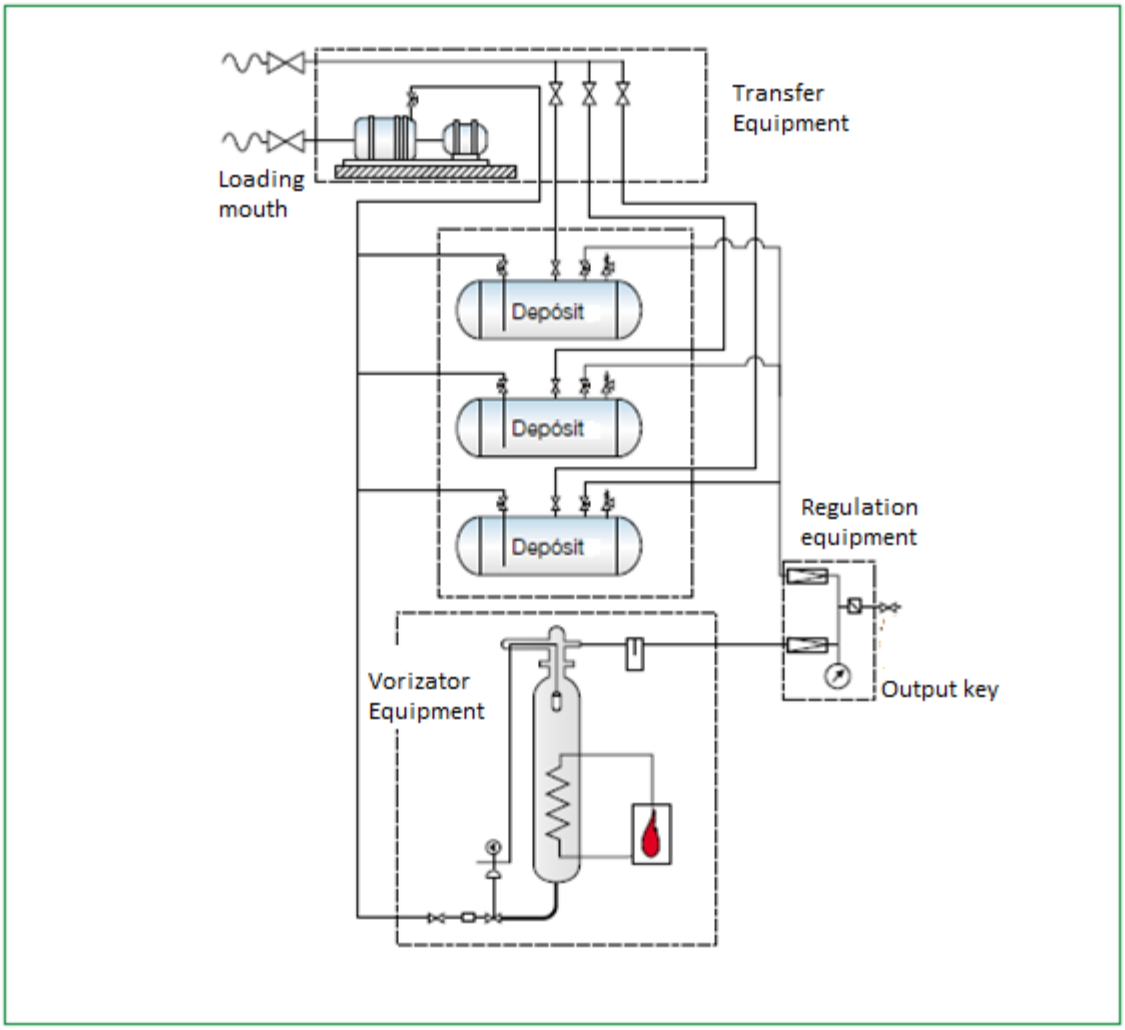
1.4 Pic 1: Distribution of pressure of commercial butane and propane. Reference [7]

Location: It is forbidden to place deposits in basements, stairwells or busy places. There is a standard by which the deposit must be located at a safe distance of other buildings / deposits safely.

All the properties and data about LGP are taking of reference [7].

LPG storage facility components in the 1.4 Pic 2 (Reference [7]):
- Loading mouth (BC)
- Wiring between the loading mouth and the output
- Tank with accessories (D)
- Regulation equipment (ER)
- Transfer equipment (ET)
- Vaporization equipment (EV)

- Key output (Sa)



1.4 Pic 2: Installation diagram of an LPG tank. Reference [7]

1.5 Selection of materials

Here we are going to present the some different kind of fibers and matrix that we can use in the design of the deposit (References [2],[10],[11]):

Fibers Study

Here we present different kind of fibers and example of properties in 1.5 Pic 1 for build our deposit:

1) Glass fibers A,B,C,D,E,ERC,R,S y X
2) Carbon fiber
3) Boron fiber

Material	Diameter (μm)	Density (ρ) (g/cm³)	Tensile Modulus (E) (GPa)	Tensile Strength (σ) (GPa)	Specific Modulus (E/ρ)	Specific Strength	Melting Point (°C)	% Elongation at Break	Relative Cost
Fibers									
E-glass	7	2.54	70	3.45	27	1.35	1540+	4.8	Low
S-glass	15	2.50	86	4.50	34.5	1.8	1540+	5.7	Moderate
Graphite, high modulus	7.5	1.9	400	1.8	200	0.9	>3500	1.5	High
Graphite, high strength	7.5	1.7	240	2.6	140	1.5	>3500	0.8	High
Boron	130	2.6	400	3.5	155	1.3	2300	—	High
Kevlar 29	12	1.45	80	2.8	55.5	1.9	500(D)	3.5	Moderate
Kevlar 49	12	1.45	130	2.8	89.5	1.9	500(D)	2.5	Moderate
Bulk materials									
Steel		7.8	208	0.34–2.1	27	0.04–0.27	1480	5–25	<Low
Aluminum alloys		2.7	69	0.14–0.62	26	0.05–0.23	600	8–16	Low
Carburo de silicio (SiC)		3.00	400		133.4				Alto
Alúmina (Al_2O_3)		3.7	380		102.7				

1.5 pic 1: Examples of the properties of different fibers. Reference [10]

Comparing the E type fiberglass with steel using 1.5 Pic 1, we can see that the ratio between the modulus of elasticity and the density is 27 for both materials, which shows that in relative terms, are similar, in spite of not being in absolute terms. Although boron fiber and carbon steel offer superior properties, their cost is much higher, so the glass fiber is one of the best options. Fiberglass-> isotropic material, currently only silicate glasses (50/60% SiO2) are important, but the type of reinforcement used in industrial applications due to high availability, good mechanical properties and relatively low cost / benefits.

In his behavior as fiber has low density, high mechanical strength , high electrical resistance, chemical inertia and moisture inertia, and incombustibility.

	Composition (%)				
	A	C	E	R	S
SiO_2	72.0	64.6	52.4	60.0	64.4
Al_2O_3,Fe_2O_3	1.5	4.1	14.4	25.0	25.0
CaO	10.0	13.4	17.2	9.0	-
MgO	2.5	3.3	4.6	6.0	10.3
Na_2O,K_2O	14.2	9.6	0.8	-	0.3
B_2O_3	-	4.7	10.6	-	-
BaO	-	0.9	-	-	-
Specific weight	2.45	2.45	2.56	2.58	2.49
Refractive index	1.512	1.520	1.548	-	1.523
Tensile strenght of a fiber (Gpa)	3.1	-	3.6	4.4	4.5
Modulus of elasticity of a fiber (Gpa)	72	-	76	85	86
Softening point (ºC)	700	690	850	990	-

1.5 Pic 2 : Examples of composition of glasses fibers. Reference [11]

Some properties of these glasses are (Reference [11]):
Glass A: used as reinforcement and has high chemical resistance
Glass B: excellent electrical properties and high durability.
Glass E: Good electrical insulation, good mechanical and chemical properties.
Glass ERC: Good electrical insulation, and good resistance to chemical corrosion.
Glass C: High resistance to chemical corrosion
Glass A: High mechanical strength and modulus of elasticity
Glass D: High dielectric

The fibers were classified according to the BS / ISO (Reference [11]).

EXAMPLE:
"EC December 40 2400" continuous E-glass fiber, yarn nomial diameter of 12 microns, with a weight of 40 gr thread per 1000 meters and has a total weight of 2400 grams per 1000 meters.

Humidity decreases the fiber strength so you have to put an insulator, and are susceptible to static fatigue (prolonged static load) so you have to keep in mind that at the time of design.
The most common resins are polyester, epoxy and phenolic. They are quite inexpensive and are available in a variety of fiber reinforced resins formas.Las glass are widely used in the construction industry. Known as fiber reinforced plastics (GRP) are used as coating or other structural materials as part of one wall panel structure. Also used commonly in the chemical storage tanks

Matrix Study

	Density (Mg/m^3)	*Young's modulus* (GPa)	*Strength*[a] (MPa)	*Ductility* (%)	*Toughness* K_{IC} ($MPa\ m^{1/2}$)	*Specific modulus* [$(GPa)/(Mg/m^3)$]	*Specific strength* [$(MPa)/(Mg/m^3)$]
CERAMICS							
Alumina Al_2O_3	3.87	382	332	0	4.9	99	86
Magnesia MgO	3.60	207	230	0	1.2	58	64
Silicon Nitride Si_3N_4		166	210	0	4.0		
Zirconia ZrO_2	5.92	170	900	0	8.6	29	152
β-Sialon	3.25	300	945	0	7.7	92	291
Glass-ceramic Silceram	2.90	121	174	0	2.1	42	60
METALS							
Auminium	2.70	69	77	47		26	29
Aluminium-3%Zn-0.7%Zr	2.83	72	325	18		25	115
Brass Cu-30%Zn	8.50	100	550	70		12	65
Nickel-20%Cr-15%Co	8.18	204	1200	26		25	147
Steel mild	7.86	210	460	35		27	59
Titanium-2.5% Sn	4.56	112	792	20		24	174
POLYMERS							
Epoxy	1.12	4	50	4	1.5	4	36
Melamine formaldehyde	1.50	9	70			6	47
Nylon 6.6	1.14	2	70	60		18	61
Polyetheretherketone	1.30	4	70			3	54
Polymethylmethacrylate	1.19	3	50	3	1.5	3	42
Polystyrene	1.05	3	50	2	1.0	3	48
Polyvinylchloride rigid	1.70	3	60	15	4.0	2	35

[a]Strength values are obtained from the test appropriate for the material, e.g., flexural and tensile for ceramics and metals respectively.

1.5 Pic 3: Example of properties of different matrix. Reference [11].

After the studio of the different matrices, we chose the epoxy matrix because they have greater strength and elastic properties with less shrinkage on cure and a lower coefficient of thermal expansion, apart from having a bond strength fiber / resin greater than other types of matrix , this together with the fact that the epoxy matrices are cheap and easy to find.

Property	Units	Epoxy Resins	Polyester Resins
Density	$Mg\ m^{-3}$	1,1-1,4	1,2-1,5
Young Modulus	$GN\ m^{-2}$	3-6	2-4,5
Poisson relation		0,38-0,4	0,37-0,39
Tensile Strenght	$MN\ m^{-2}$	35-100	40-90
Compression strenght	$MN\ m^{-2}$	100-200	90-250
Tensile alargation at break	%	1-6	2
Thermic conductivity	$W\ m^{-1}{}^{\circ}C_{-1}$	0,1	0,2
Coefficient of thermal expansion	$10^{-6}\ {}^{\circ}C^{-1}$	60	100-200
Heat distortion temperature	°C	50-300	50-110
Curing shringkage	%	1-2	4-8
Water Absorption (24h. at 20°C)	%	0,1-0,4	0,1-0,3

1.5 Pic 4: Comparison of Epoxy resins and Polyester resins. Reference [10]

1.6 Final idea

After the study of the fibers and the matrix, we choose Glass fibers and Epoxy matrix with the following characteristics:

	ρ (kg/m3)	E(Gpa)	$\sigma_R^t(Gpa)$	ε_R	α	ν	Vol(%)	Price	
Glass Fiber (Glass R)	2500	86	3.2	5	$0.3 \cdot 10^{-5}$	0.22	0.7	15€/kg	
Epoxi Matrix	1200	5	0.13	6	$9 \cdot 10^{-5}$	0.33	0.3	3€/kg	

All the data about properties of fibers and matrix in this paragraph is got it from **reference [2]** following the next picture **1.6 Pic 1**:

MATERIAL	ρ (kg/m³)	E (GPa)	σ_R^t (GPa)	ε_R	α (ºC⁻¹)0	K (W/mºC)	Precio (pts/kg)
			METALES				
steel	7800	205	0.4 ÷ 1.6	1.8	$1.3 \cdot 10^{-5}$	20 ÷ 100	100
light aluminum alloy	2800	75	0.45	-	$2.2 \cdot 10^{-5}$	80 ÷ 150	500
copper	8600	125	0.2 ÷ 0.5	-	$1.7 \cdot 10^{-5}$	380	-
glass R	2500	86	3.2	5.0	$0.3 \cdot 10^{-5}$	1	2500
glass E	2600	74	2.5	4.5	$0.5 \cdot 10^{-5}$	1	1000
carbon HR	1750	230	3.2	1.3	$0.02 \cdot 10^{-5}$	100÷200	30000
carbon HM	1800	390	2.5	0.6	$0.08 \cdot 10^{-5}$	100÷200	35000
boron	2600	400	3.4	0.8	$0.04 \cdot 10^{-5}$	-	70000
Cerámic.	3900	380	1.4	0.4	-	-	-
Aramid	1450	130	2.9	2.6	$0.2 \cdot 10^{-5}$	0.03	10000
Polypropylene	900	1.1 ÷ 1.4	0.025	-	-	-	-
Polyamide	1200	2.7	0.075	17	$8.5 \cdot 10^{-5}$	0.06	-
Polycarbonate	1200	2.4	0.06	-	-	-	-
Phenolic	1300	3.0	0.04	-	-	-	-
Epoxy	1200	4 - 5	0.13	3 ÷ 6	$9 \div 13 \cdot 10^{-5}$	-	800
Polyester	1200	4	0.06 ÷ 0.1	2.5	$2 \cdot 10^{5}$	0.021	800

1.6 Pic 1: Properties of Fibers and Matrix. Reference [2]

1.7 Examples

I`m going to present some examples of composite structures:

1) Glasgow Science Tower (1.7 Pic 1)

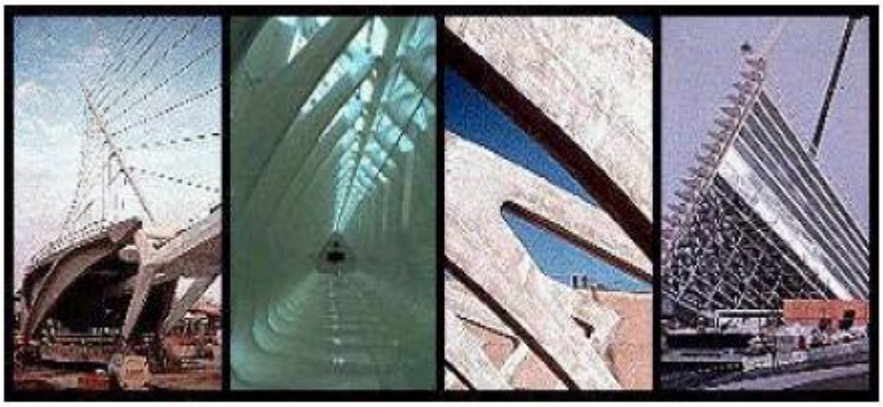
1.7 Pic 1: Glasgow Science tower.Reference [6]

It is a tower of 120 m height whose top rotates freely in the wind. For reasons of weight the upper part is made of glass fiber and mast is made by carbon fiber.

2) Milwaukee art (1.7 Pic 2)

Art museum of Milwaukee (2001) designed by Santiago Calatraba.

It has mobile wings 32m in length to allow the light to the gallery museum. These wings are formed by rudders 72 of 0.6 m in thickness and of varying lengths between 32 and 8m. These rudders were projected carbon / epoxy using curl filamentary but were manufactured in stainless for economic issues.



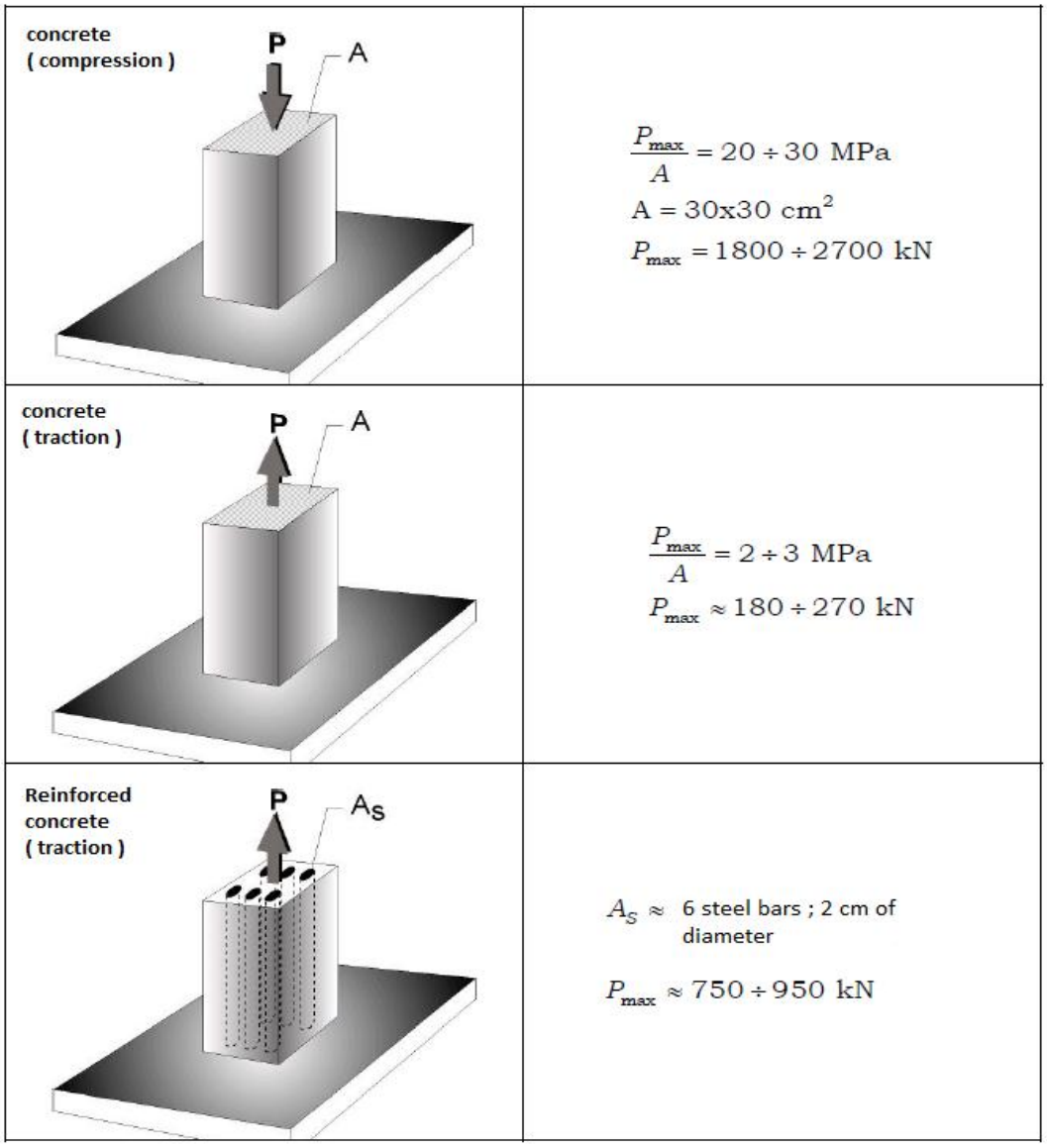
1.7 Pic 2: Milwaukee Art. Reference [6]

2.Theorical introduction

2.1 Introduction to composite laminates

A composite material is formed from two or more materials having better properties than the constituent material individually. For giving an example, we can think in "reinforced concrete".

Concrete, by itself, resists well compressive stresses, but not resists traction stresses. However, the steel is so good resisting traction stresses, so the combination of both materials give us a perfect material for structures that suffer flexion , and therefore , traction stresses.



2.1 Pìc 1: Example of reinforce concrete. Reference [1]

According to the definition given before of composite, practically all the materials that are used in engineering can be considered composite.

Taking in count the properties of the composite in the reference [2], this are the most important properties for engineering:

- Mechanical resistance
- Stiffness
- Resistance to corrosion
- Wear resistance
- Lightweight
- Resistance to fatigue
- Thermal and acoustic insulation
- Artwork

Composite can be classified in different categories following the Reference [2]:

- Composite formed by a matrix with fibers of another material
- Composite laminates that consist in 2 or more laminates formed of different materials and glued each other.
- Composite formed by a matrix with particles of another material

In this project, I am going to use the first and second class, a composite formed by laminates that have a matrix and backing by large fibers of another material. I choose large fibers, because in spite of large fibers are less resistant that the whiskers, with them we can orientate the direction of the stress.

In the 2.1 Pic 2 we can see the properties of different material which we can build composite.

MATERIAL	ρ (kg/m³)	E (GPa)	σ_R^t (GPa)	ε_R	α (°C⁻¹)0	K (W/m°C)	Precio (pts/kg)
			METALES				
steel	7800	205	0.4 ÷ 1.6	1.8	$1.3 \cdot 10^{-5}$	20 ÷ 100	100
light aluminum alloy	2800	75	0.45	-	$2.2 \cdot 10^{-5}$	80 ÷ 150	500
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Cerámic.	3900	380	1.4	0.4	-	-	-
Aramid	1450	130	2.9	2.6	$0.2 \cdot 10^{-5}$	0.03	10000
Polypropylene	900	1.1 ÷ 1.4	0.025	-	-	-	-
Polyamide	1200	2.7	0.075	17	$8.5 \cdot 10^{-5}$	0.06	-
Polycarbonate	1200	2.4	0.06	-	-	-	-
Phenolic	1300	3.0	0.04	-	-	-	-
Epoxy	1200	4 - 5	0.13	3 ÷ 6	$9 \div 13 \cdot 10^{-5}$	-	800
Polyester	1200	4	0.06 ÷ 0.1	2.5	$2 \cdot 10^5$	0.021	800

2.1 Pic 2 : Properties of Fibers and Matrix. Reference [2]

2.2 Micromechanical Aspects of Composite

In this section we study the mechanics behavior of the composites according to their constituents following the reference [2], taking in count that the basic unit of this type of material is the "Laminate". A " laminate " is a set of sheets.

The thickness of a sheet is usually between one tenth of millimeter and one millimeter following the reference [2], and there are three types of laminates:

a) Unidirectional laminate (Parallels large fibers)
b) Bidirectional laminate (Interlocking fibers)
c) Laminate of whiskers

Now, I am going to define some important parameters for building the deposit using the reference [2] :

2.2.1 Volumetric percentage of fiber and matrix

$$V_{fibers} = \frac{Fibers\ Volume}{Total\ Volume} \qquad (1)$$

$$V_{matrix} = \frac{matrix\ Volume}{Total\ Volume} \qquad (2)$$

$$V_{fibers} + V_{matrix} = 1 \qquad (3)$$

The usual volumetric content of fibers for composite as a function of the processing system are:

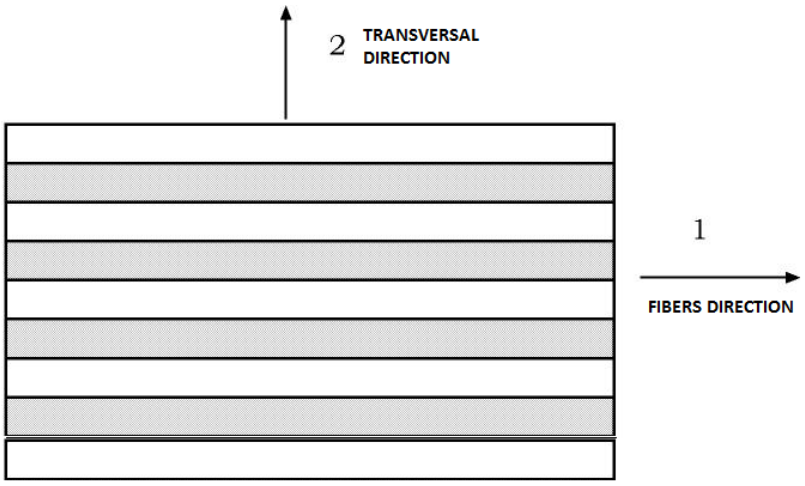
FABRICATION PROCESS	V_f (%)
by contact	30
by pressure	40
filament winding	60-85
by vacuum bag	50-80

2.2.1 Pic 1: Fabrication process in function of percent of fibers. Reference [2]

2.2.2 Elastic Properties

The sheets, and therefore the laminates, presents anisotropic behavior. This means that the way how an anisotropic sheet suffers the stress and deform because of this stress depends in the direction that we are measuring.

Taking in count this property, that fibers and matrix are considered homogeneous, isotropic and linear-elastic behavior, we have the next macromechanic properties:



2.2.2 Pic 1: Representation of local axes in the laminate. Reference [2]

- Elastic modulus in the fibers direction

$$E_1 = E_{fibers} \cdot V_{fibers} + E_{matrix} \cdot (1 - V_{fibers}) \qquad (4)$$

- Elastic modulus in fibers orthogonal direction

$$E_2 = E_{matrix} \cdot \left(\frac{1}{(1 - V_{fibers}) + \frac{E_{matrix}}{E_{fibers}} \cdot V_{fibers}} \right) \qquad (5)$$

- Main poisson coefficient

$$\nu_{21} = \nu_{fibers} \cdot V_{fibers} + \nu_{matrix} \cdot (1 - V_{fibers}) \qquad (6)$$

- Secondary poisson coefficient

$$\frac{\nu_{12}}{E_2} = \frac{\nu_{21}}{E_1} \qquad (7)$$

- Transversal Stiffness modulus

$$G_{12} = G_{matrix} \cdot \left(\frac{1}{V_{matrix} + V_{fibers} \cdot \frac{G_{matrix}}{G_{fibers}}} \right) \qquad (8)$$

- Coefficient of thermal expansion in fibers direction

$$\alpha_1 = \frac{\alpha_{fibers} \cdot E_{fibers} \cdot V_{fibers} + \alpha_{matrix} \cdot E_{matrix} \cdot V_{matrix}}{E_{fibers} \cdot V_{fibers} + E_{matrix} \cdot V_{matrix}} \qquad (9)$$

- Coefficient of thermal expansion in transversal direction

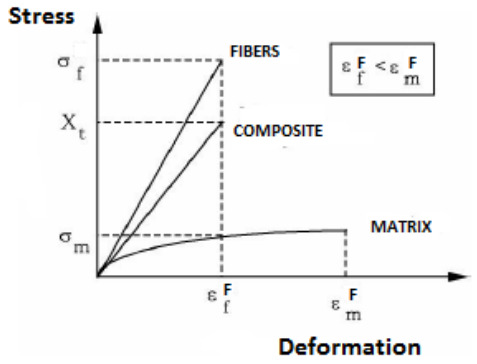
$$\alpha_2 = \alpha_{matrix} \cdot V_{matrix} + \alpha_{fibers} \cdot V_{fibers} + \frac{(\nu_f \cdot E_m - \nu_m \cdot E_f)}{\frac{E_m}{V_f} + \frac{E_f}{V_m}} \cdot (\alpha_f - \alpha_m) \qquad (10)$$

2.2.3 Traction in the sheet in fibers direction

If the sheet is suffering a traction stress, we have two options:

a) The fiber has a lower failure strain than the matrix

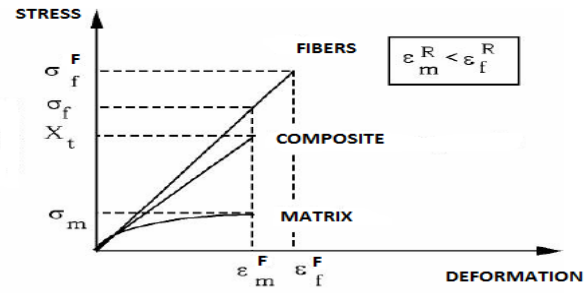
$$\varepsilon^F_{fibers} < \varepsilon^F_{matrix}$$



2.2.3 Pic 1: Stress-Deformation Diagram for a composite with less elongation at break for the fibbers. Reference [2]

b) The matrix has lower failure strain than the fibers

$$\varepsilon^F_{matrix} < \varepsilon^F_{fibers}$$



2.2.3 Pic 1: Stress-Deformation Diagram for a composite with less elongation at break for the fibbers. Reference [2]

For our percent of fibers (70%), all the resistance in traction is exerted by fibers, so we have to follow the next equation for knowing the resistance in traction:

$$V_m < V_f \rightarrow X_t = V_f \cdot \sigma_{fibers}^R \qquad (11)$$

2.2.4 Traction in orthogonal direction of fibers. Resistance

Following the reference [2] we have the following resistance in this direction:

$$V_m < V_f \rightarrow Y_t = V_m \cdot \sigma_{matrix}^R \qquad (12)$$

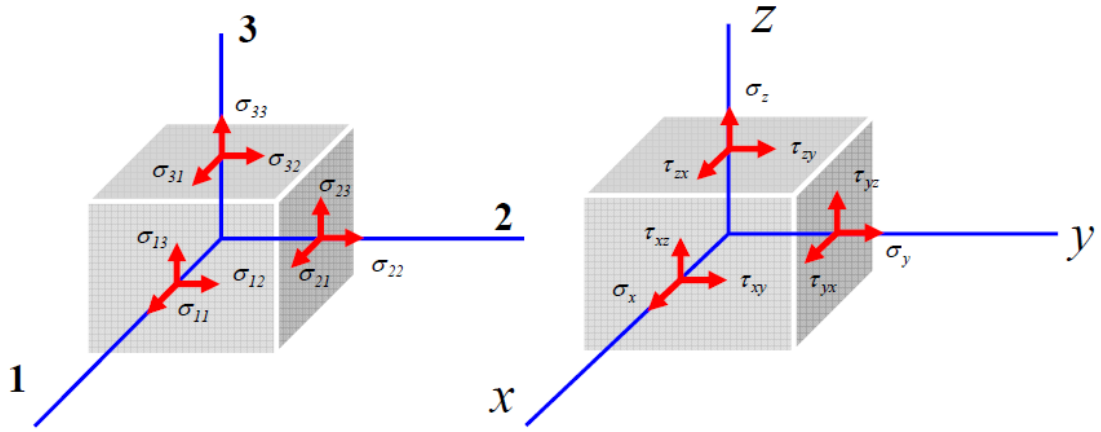
2.3 Macromechanic Study of a sheet

In this paragraph we are going to explain the notation that we will use for the design.

2.3.1 Stress tensor and Strain tensor

Stress tensor

$$[T] = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix} \qquad (13)$$



2.3.1 Pic 1: Representation of the stresses in cubic differential of material. Reference [2]

Strain tensor

In the same directions than the Stress tensor:

$$[T] = \begin{bmatrix} \varepsilon_x & \gamma_{xy} & \gamma_{xz} \\ \gamma_{yx} & \varepsilon_y & \gamma_{yz} \\ \gamma_{zx} & \gamma_{zy} & \varepsilon_z \end{bmatrix} = \begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{bmatrix} \qquad (14)$$

2.3.2 Constitutive Equations

If the material presents and elastic and isotropic behavior,

we can apply the **Hooke`s Law**:

$$\varepsilon_x = \frac{\sigma_x}{E} - \frac{\nu}{E} \cdot (\sigma_y + \sigma_z) \quad (15)$$

$$\varepsilon_y = \frac{\sigma_y}{E} - \frac{\nu}{E} \cdot (\sigma_z + \sigma_z) \quad (16)$$

$$\varepsilon_z = \frac{\sigma_z}{E} - \frac{\nu}{E} \cdot (\sigma_x + \sigma_y) \quad (17)$$

$$\gamma_{xy} = \frac{\tau_{xy}}{G} \quad (18)$$

$$\gamma_{zx} = \frac{\tau_{zx}}{G} \quad (19)$$

$$\gamma_{yz} = \frac{\tau_{yz}}{G} \quad (20)$$

Or the **Lame`s equations** :

$$\sigma_x = \lambda \cdot e_v + 2 \cdot G \cdot \varepsilon_x \quad (21)$$

$$\sigma_y = \lambda \cdot e_v + 2 \cdot G \cdot \varepsilon_y \quad (22)$$

$$\sigma_z = \lambda \cdot e_v + 2 \cdot G \cdot \varepsilon_z \quad (23)$$

$$\gamma_{xy} = \frac{\tau_{xy}}{G} \quad (24)$$

$$\gamma_{zx} = \frac{\tau_{zx}}{G} \quad (25)$$

$$\gamma_{yz} = \frac{\tau_{yz}}{G} \quad (26)$$

2.3.3 Stiffness matrix of the sheet

Stiffness matrix of a unidirectional lamina in local axes

$$[Q] = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{SS} \end{bmatrix} = \begin{bmatrix} \frac{E_1}{1-\nu_{12}\cdot\nu_{21}} & \frac{\nu_{21}\cdot E_2}{1-\nu_{12}\cdot\nu_{21}} & 0 \\ \frac{\nu_{12}\cdot E_1}{1-\nu_{12}\cdot\nu_{21}} & \frac{E_2}{1-\nu_{12}\cdot\nu_{12}} & 0 \\ 0 & 0 & G_{12} \end{bmatrix} \quad (27)$$

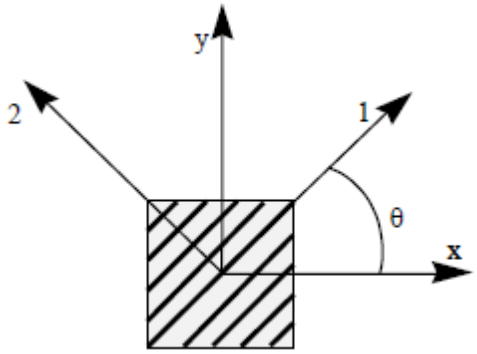
$[Q]$ → Local axis // $\overline{[Q]}$ → Global axis

2.3.4 Change axes matrix

$$[T] = \begin{bmatrix} c^2 & s^2 & 2 \cdot c \cdot s \\ s^2 & c^2 & -2 \cdot c \cdot s \\ -s \cdot c & s \cdot c & (c^2 - s^2) \end{bmatrix} \qquad (28)$$

$$[T]^{-1} = \begin{bmatrix} c^2 & s^2 & -2 \cdot c \cdot s \\ s^2 & c^2 & 2 \cdot c \cdot s \\ s \cdot c & -s \cdot c & (c^2 - s^2) \end{bmatrix} \qquad (29)$$

s = sin(θ) c = cos(θ)



2.3.4 Pic 1: Example of change the axes from global to local axes. Reference [2]

$$\begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{pmatrix} = [T] \cdot \begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix} \qquad (30)$$

$$\begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \frac{1}{2}\gamma_{12} \end{pmatrix} = [T] \cdot \begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \frac{1}{2}\gamma_{xy} \end{pmatrix} \qquad (31)$$

$$\begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{pmatrix} = [Q] \cdot \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{pmatrix} \qquad (32)$$

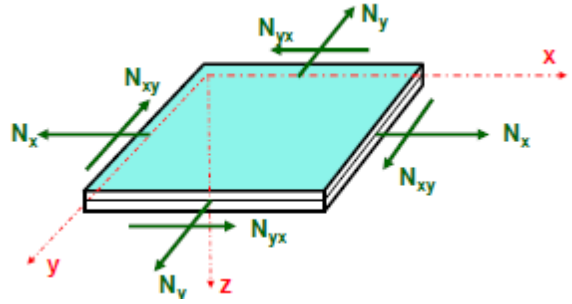
2.3.5 Classic theory of Laminates. Kirchoff hypothesis

Kirchoff Hypothesis . (Reference [2])

1- The perpendicular lines to the median plane, before the laminate deform, continue being straight after the laminate has deformed.
2- The perpendicular lines to the median plane don't suffer any longitudinal deformation (the thickness of the laminate don't change)
3- The perpendicular lines to the median plane continue being perpendicular after the laminate deflect.

2.3.6 Load vector. Momentum vector. Global equation

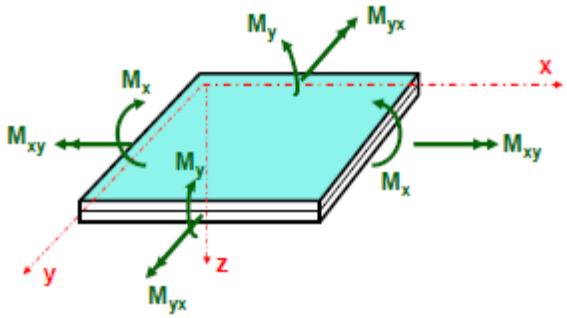
Load vector (per unit of width)



2.3.6 Pic 1: Efforst plane diagram in a sheet .Reference [2]

$$(N) = \begin{pmatrix} N_x \\ N_y \\ N_{xy} \end{pmatrix} \quad [N/m] \qquad (33)$$

Momentum vector(per unit of width)



2.3.6 Pic 1: Efforst plane diagram in a sheet. Reference [2]

$$(M) = \begin{pmatrix} M_x \\ M_y \\ M_{xy} \end{pmatrix} \quad [N \cdot m/m] \qquad (34)$$

Global equation

$$\begin{pmatrix} N \\ M \end{pmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \begin{pmatrix} \varepsilon^0 \\ k \end{pmatrix} \qquad (35)$$

Notation:

- h : thickness of the sheet
- z : distance to the medium plane
- k : curvature
- ε^0 : medium plane deformation

$$(N) = [A] \cdot (\varepsilon^0) + [B] \cdot (k) \qquad (36)$$

$$(M) = [B] \cdot (\varepsilon^0) + [D] \cdot (k) \qquad (37)$$

Stiffness matrix

$$[A] = \sum_i \overline{[Q]}_i \cdot h_i \qquad (38)$$

Coupling matrix

$$[B] = \sum_i \overline{[Q]}_i \cdot \frac{1}{2} \cdot (z_i^2 - z_{i-1}^2) \qquad (39)$$

Bending stiffness matrix

$$[D] = \sum_i \overline{[Q]}_i \cdot \frac{1}{3} \cdot (z_i^3 - z_{i-1}^3) \qquad (40)$$

2.3.7 Failure criteria

Notation:

$X_t = Longitudinal\ Tensile\ Strenght$

$X_c = Longitudinal\ compressive\ Strenght$

$Y_t = Transverse\ tensile$

$Y_C = Transverse\ compressive\ strenght$

$S = Maximum\ shear\ stress\ in\ the\ 1-2\ plane1$

$X_{\varepsilon_t} = Maximum$ longitudinal tensile strain in direction 1

$X_{\varepsilon_c} = Maximum$ longitudinal strain at compression in direction 1

$Y_{\varepsilon_T} = Maximum$ longitudinal tensile strain in direction 2

$Y_{\varepsilon_c} = Maximum$ longitudinal strain at compression in direction 2

$S_\varepsilon = Maximum\ shear\ strain\ in\ the\ 1-2\ plane1$

Examples of the strength of different materials in 2.3.7 Pic 1

	Glass	Aramid	Carbon
Densidad (kg/m^3)	2080	1350	1530
X_t (MPa)	**1250**	**1410**	**1270**
X_c (MPa)	600	280	1130
Y_t (MPa)	**35**	**28**	**42**
Y_c (MPa)	141	141	141
E_1 (GPa)	**45**	**85**	**134**
E_2 (GPa)	**12**	**56**	**7**
α_1 $(°C)^{-1}$	0.4÷0.7x10^{-5}	-0.4x10^{-5}	-0.12x10^{-5}
α_2 $(°C)^{-1}$	1.6÷2.0x10^{-5}	5.8x10^{-5}	3.4x10^{-5}

2.3.7 Pic 1: Examples of Resistance properties of some fibers

1) Maximum stress criterion

The sheet will not break while:

$$-X_c < \sigma_1 < X_t \qquad (41)$$

$$-\mathrm{Y_c} < \sigma_2 < \mathrm{Y_t} \qquad (42)$$

$$|\tau_{\max}| < S \qquad (43)$$

2) Maximum deformation criterion

The sheet will not brake while:

$$-X_{\varepsilon_c} < \varepsilon_1 < X_{\varepsilon_t} \qquad (44)$$

$$-Y_{\varepsilon_c} < \varepsilon_2 < Y_{\varepsilon_t} \qquad (45)$$

$$|\gamma_{\max}| < S_\varepsilon \qquad (46)$$

3) Tsai-Hill criterion

The sheet will not brake while:

$$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n} \qquad (47)$$

Being " n " the security coefficient.

3. Design of the deposit

3.1 Study the behavior of LGP in a tank and the induced stresses

We know that the deposit will save LGP, partially in gas phase and almost full of liquid LGP. We know that the LGP gas is so dangerous, because a little increase of temperature produce huge increase of pressure.

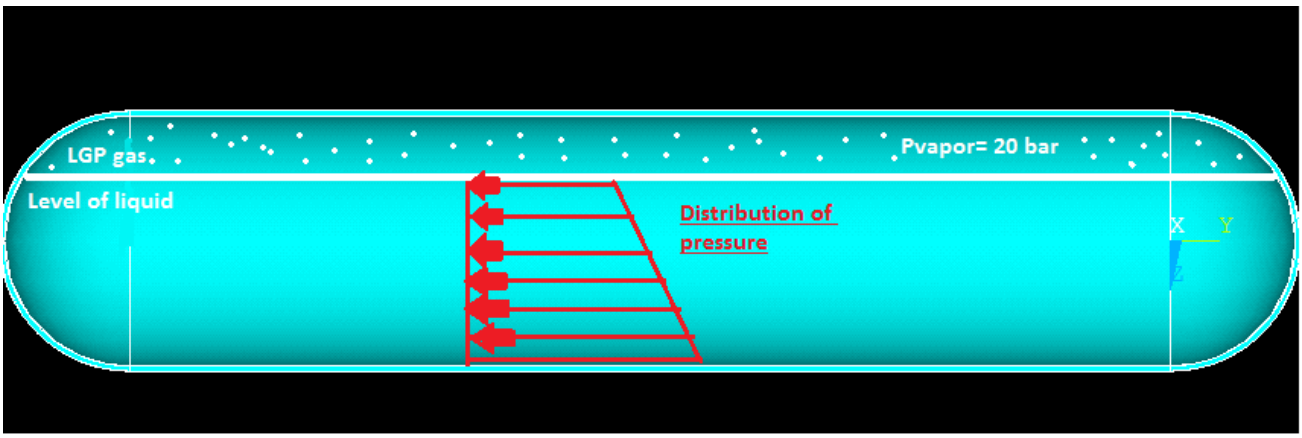
Between the propane and the methane, the propane is the most dangerous , because at 60ºC the pressure in gas phase is 21 bar. For the methane is 7.5 bar at 60ºC following reference [7].

So , we are going to suppose the worse possible situation for our deposit:

- Maximum quantity of LGP liquid (85% of the total volume)

- Vapor pressure of 21 bar at 60 ºC

So making the study of distribution of pressure in the deposit:



3.1 Pic 1: Scheme of the distribution of pressure in the deposit

The distribution of pressure in the deposit will be like in 3.1 Pic 1 and the equation will be (Reference [21]):

$$p(z) = p_{vapor}^{LGP} + \rho_{liquid}^{LGP} \cdot g \cdot z \qquad 0 \leq z \leq 1\ (m) \qquad (48)$$

$$\rho_{liquid} = 0.559 \frac{kg}{l} \cdot 1 \frac{l}{dm^3} \cdot 10^3 \frac{dm^3}{m^3} = 559 \frac{kg}{m^3}$$

So the maximum pressure that must resist our deposit will be:

$$p_{maximum} = 21 \cdot 10^5 (Pa) + 559 \frac{kg}{m^3} \cdot 9.8 \frac{m}{s^2} \cdot 1\ m = 20.027391 \cdot 10^5 (Pa) = 21.027\ bar$$

This is in the pressure in the vessel bottom.So we know that our deposit must resist minimum a pressure around 21 bar. We made the study for a temperature of 60ºC, that is higher than the service temperature, that will be around 45ºC, so we are prepared for possible changes in the temperature that will produce huge changes in the pressure.

Take in count that the pressure in a gas or a liquid, is always orthogonal to the surface of the vessel where is contained.

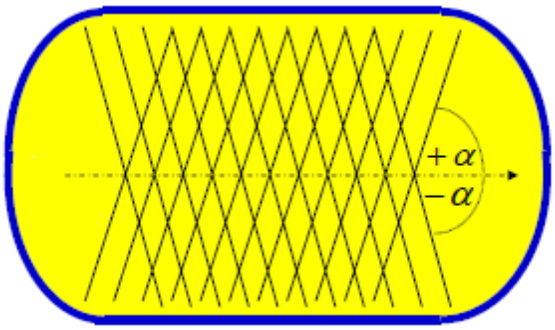
Now that we know the worse situation of pressure for our deposit, we are going to design the deposit taking in count a **pressure of 30 bar with a security coefficient of 3.** This will give us the security that even with variations of temperature, pressure, quantity of liquid or gas or the kind of fluid, we will have a range of security in service. In this paragraph we also used the reference [16] for making a correct design.

3.2 Optimal orientation of fibers

We know that we will have normal stresses and tangential stresses, so we have to choose a combination of fibers in which the orientation must support this stresses.

We are going to study for a orientation where the laminate only have to support normal stresses in the fibers direction, not have to support tangential stresses.

The first step is consider that exist this orientation:



3.2 Pic 1: Representation of the orientation of fibers in a deposit. Reference [2]

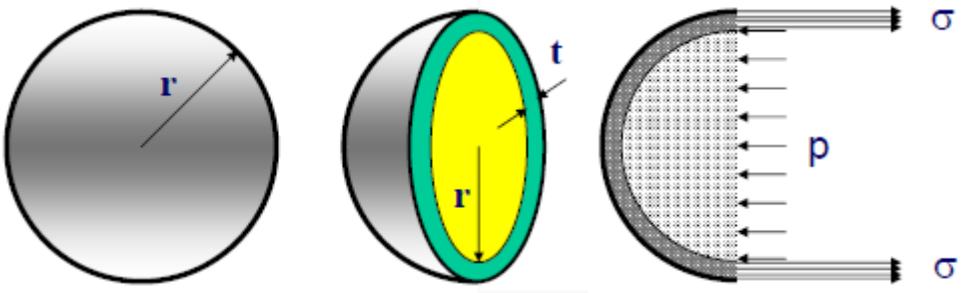
IMPORTANT APROXIMATION

In the next calculus we are going to consider a constant distribution of pressure. We know that in the deposit is not like that because we have a lineal distribution, but we can do it because we made the study before for knowing the maximum pressure induced with the lineal distribution and it was 21 bar.

Now we are going to consider a constant pressure of 30 bar , so this situation is worse than with the lineal distribution, so if our deposit is prepared for this situation, it will be prepared for the official situation.

Taking in count the stresses in:

spheric deposits:

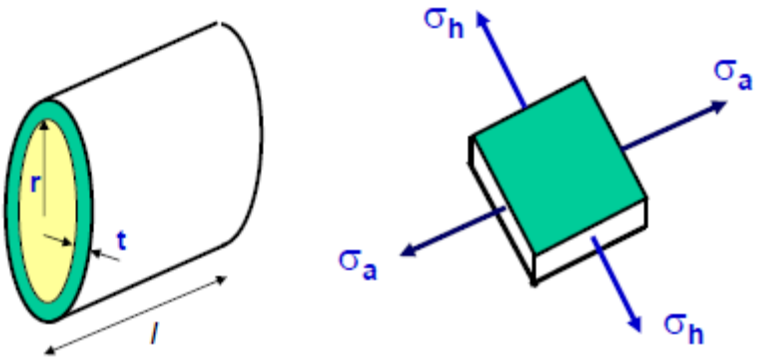


3.2 Pic 2: Distribution of pressure in a spherical deposit. Reference [2]

Stress equilibrium

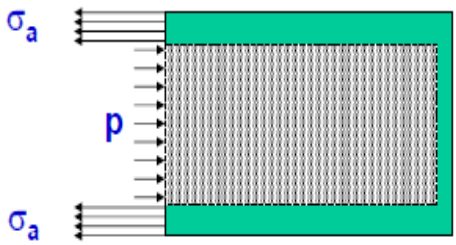
$$2\pi rt\sigma = \pi r^2 p \quad \rightarrow \quad \sigma = \frac{pr}{2t} \qquad (49)$$

Cylinder deposits



3.2 Pic 3: Distribution of pressure in a cylinder deposit. Reference [2]

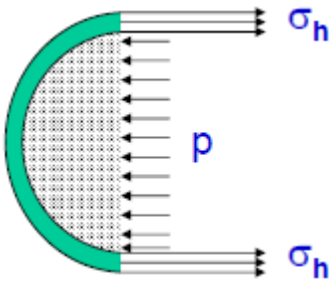
Longitudinal stress equilibrium



3.2 Pic 4: Distribution of pressure in caps of a cylinder deposit. Reference [2]

$$2\pi rt\sigma_a = \pi r^2 p \quad \rightarrow \quad \sigma_a = \frac{pr}{2t} \qquad (50)$$

Circumferential stress equilibrium



3.2 Pic 3: Distribution of pressure in circumferential axis of a cylinder deposit. Reference [2]

$2lt\sigma_h = 2rlp \rightarrow \sigma_h = \frac{pr}{t}$ *(51)*

Using the change axis matrix we can calculate the stresses in Global axes for +α laminate:

$\sigma_a^{+\alpha} = \frac{\sigma}{2}(1 + \cos 2\alpha)$ *(52)*

$\sigma_h^{+\alpha} = \frac{\sigma}{2}(1 - \cos 2\alpha)$ *(53)*

$\tau_{ah}^{+\alpha} = \frac{\sigma}{2}(\sin 2\alpha)$ *(54)*

Using the change axis matrix we can calculate the stresses in Global axes for -α laminate:

$\sigma_a^{-\alpha} = \frac{\sigma}{2}(1 + \cos 2\alpha)$ *(55)*

$\sigma_h^{-\alpha} = \frac{\sigma}{2}(1 - \cos 2\alpha)$ *(56)*

$\tau_{ah}^{-\alpha} = -\frac{\sigma}{2}(\sin 2\alpha)$ *(57)*

So, the effort will be:

$\{N\} = \sum_i \{\sigma\}_i \cdot h_i$ *(58)*

$N_a = \frac{\sigma}{2}(1 + \cos 2\alpha) \cdot 2nh_0$ *(59)*

$N_h = \frac{\sigma}{2}(1 - \cos 2\alpha) \cdot 2nh_0$ *(60)*

$N_{ah} = 0$ *(61)*

Notation:

n = number of sheets with +α or –α orientation.

h_0 = Sheet thickness

Equilibrium:

$$N_a = \frac{\sigma}{2}(1 + \cos 2\alpha) \cdot 2nh_0 = \frac{p \cdot r}{2} \qquad (62)$$

$$N_h = \frac{\sigma}{2}(1 - \cos 2\alpha) \cdot 2nh_0 = p \cdot r \qquad (63)$$

Dividing $\frac{N_a}{N_h}$:

$$\frac{(1+\cos 2\alpha)}{(1-\cos 2\alpha)} = \frac{1}{2} \rightarrow \alpha = 54.74º$$

All this calculus are based in the reference [2].

3.3 Optimal thickness. Optimal number of sheets

For getting the optimal thickness and optimal number of sheets we have to follow the next procedure:

a) Properties of Fibers and Matrix (Reference [2] in paragraph 1.6)

	ρ (kg/m3)	E(Gpa)	$\sigma_R^t(Gpa)$	ε_R	α	ν	Vol(%)	Price	
Glass Fiber (Glass R)	2500	86	3.2	5	$0.4 \cdot 10^{-5}$	0.22	0.7	15€/kg	
Epoxi Matrix	1200	5	0.13	6	$9 \cdot 10^{-5}$	0.33	0.3	3€/kg	

b) Properties of the laminate (Followin the paragraph 2.2 with reference [2])

	$E_1(Gpa)$	$E_2(Gpa)$	$G_{12}(Gpa)$	ν_{12}	ν_{21}	α_1	ρ (kg/m3)
Laminate	61.7	14.67	5.572	0.253	0.06017	$5.358 \cdot 10^{-6}$	2110

c) Stiffness matrix

Stiffness matrix in local axes:

$$[Q] = \begin{bmatrix} 62.6537 & 3.77 & 0 \\ 3.77 & 14.902 & 0 \\ 0 & 0 & 5.572 \end{bmatrix} (Gpa) \qquad \text{[eq. (27)]}$$

Stiffness matrix in global axes for sheets of +54.74º :

$$[\bar{Q}] = \begin{bmatrix} 20.21145 & 14.3751 & 7.5032 \\ 14.3751 & 36.1354 & 15.00562 \\ 7.5032 & 15.00562 & 16.17703 \end{bmatrix} (Gpa) \qquad \text{[eq. (30,(31) and (32)]}$$

Stiffness matrix in global axes for sheets of -54.74º :

$$[\bar{Q}] = \begin{bmatrix} 20.21145 & 14.3751 & -7.5032 \\ 14.3751 & 36.1354 & -15.00562 \\ -7.5032 & -15.00562 & 16.17703 \end{bmatrix} (Gpa) \qquad \text{[eq. (30,(31) and (32)]}$$

Stiffness matrix of the laminate

$$[A] = \begin{bmatrix} 40.4229 & 28.7502 & 0 \\ 28.7502 & 72.2708 & 0 \\ 0 & 0 & 32.35406 \end{bmatrix} \cdot nh \ (Gpa \cdot m) \qquad \text{[eq.(38)]}$$

n = Number of sheets

h = thickness of each sheet

Efforts in the laminate:

Dimensions of the deposit: Length : 5 meters , Radio : 0.5 meters

$$\{N\} = \begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{Bmatrix} N_z \\ N_a \\ N_{az} \end{Bmatrix} = \begin{Bmatrix} \frac{p \cdot r}{2} \\ p \cdot r \\ 0 \end{Bmatrix} = \begin{Bmatrix} \frac{p \cdot r}{2} \\ p \cdot r \\ 0 \end{Bmatrix} = \begin{Bmatrix} 750000 \\ 1500000 \\ 0 \end{Bmatrix} (\text{N}) \qquad \text{[eq.(33)]}$$

Calculation of strain and stress

$$\{N\} = [A] \cdot \begin{Bmatrix} \varepsilon_z \\ \varepsilon_a \\ \varepsilon_{az} \end{Bmatrix} \rightarrow \{\bar{\varepsilon}\} = [A]^{-1} \cdot \{N\} = \begin{pmatrix} 5.28814 \cdot 10^{-6} \\ 1.8651575 \cdot 10^{-5} \\ 0 \end{pmatrix} \cdot \frac{1}{n \cdot h} \qquad \text{[eq.(36)]}$$

Change the strain to local axes for each orientation:

$$\begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \frac{1}{2}\gamma_{12} \end{pmatrix}_{54.74º} = [T] \cdot \{\bar{\varepsilon}\} = \begin{pmatrix} 1.419806211 \cdot 10^{-5} \\ 9.74165348 \cdot 10^{-6} \\ 6.2992420 \cdot 10^{-6} \end{pmatrix} \cdot \frac{1}{n \cdot h} \qquad \text{[eq.(31)]}$$

$$\begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \frac{1}{2}\gamma_{12} \end{pmatrix}_{-54.74º} = [T] \cdot \{\bar{\varepsilon}\} = \begin{pmatrix} 1.419806211 \cdot 10^{-5} \\ 9.74165348 \cdot 10^{-6} \\ -6.2992420 \cdot 10^{-6} \end{pmatrix} \cdot \frac{1}{n \cdot h} \qquad \text{[eq.(31)]}$$

Stress in local axes:

$$\begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{pmatrix}_{54.74º} = [Q] \cdot \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{pmatrix} = \begin{pmatrix} 926291.84 \\ 198708.15 \\ 35101.0011921 \end{pmatrix} \cdot \frac{1}{n \cdot h} \qquad \text{[eq.(30)]}$$

$$\begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{pmatrix}_{-54.74º} = [Q] \cdot \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{pmatrix} = \begin{pmatrix} 926291.84 \\ 198708.15 \\ -35101.0011921 \end{pmatrix} \cdot \frac{1}{n \cdot h} \qquad \text{[eq.(31)]}$$

Filure criteria for knowing how much thickness must have our deposit following the equation (47) :

$$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1 \sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{s} \qquad \text{[eq.(47)]}$$

(It will be the same for the sheet of 54.74º and -54.74º)

Properties of our laminate (calculus following Reference [2] in paragraph 2.2.3 and 2.2.4) :

	X_t (Mpa)	Y_t (Mpa)	S (Mpa)
Laminate	2240	39	63

Choosing a security coefficient as **s = 3** we will obtain:

$$2.6094166 \cdot 10^{-5} \cdot \left(\frac{1}{n \cdot h}\right)^2 = \frac{1}{3} \rightarrow n \cdot h = 8.8477 \cdot 10^{-3}$$

Now we have to possibilities:

	"n" for each orientation	**h**
Option 1	**10**	**1 mm**
Option 2	**100**	**0.1 mm**

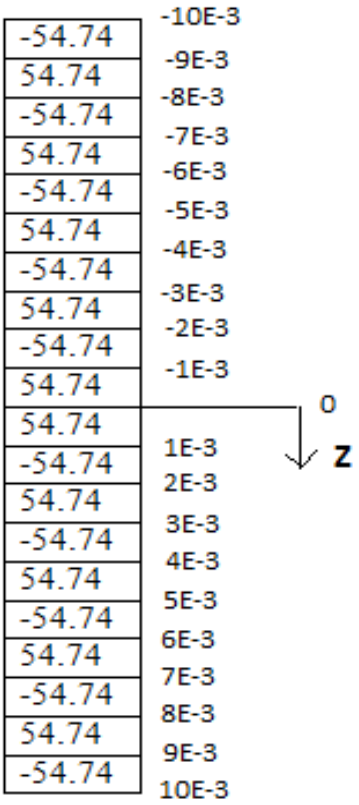
I choose the first option, because is more easy for calculating and defining the deposit. So , the characteristics of our deposit will be:

	"n" for each orientation	**h**	**thickness**
Laminate	**10**	**1 mm**	**2 cm**

Note: Take in count that is 10 sheets per orientations, so in total we will have 20 sheets, 10 per 54.74º orientation and another 10 per -54.74º.

3.4 Static analysis

Firstly we are going to define the global matrix of the deposit:



3.4 Pic 1: Position of the sheets in the laminate of the deposit

Coupling matrix

$[B] = \sum_i \overline{[Q]}_i \cdot \frac{1}{2} \cdot (z_i^2 - z_{i-1}^2) = [0]$ (SYMMETRIC LAMINATE) [eq.(39)]

Bending stiffness matrix

$$[D] = \sum_i \overline{[Q]}_i \cdot \frac{1}{3} \cdot (z_i^3 - z_{i-1}^3) = \begin{bmatrix} 13474.30596 & 9583.42519 & 0 \\ 9583.42519 & 24090.27105 & 0 \\ 0 & 0 & 10784.6867 \end{bmatrix} (Gpa \cdot m^3)$$

[eq.(40)]

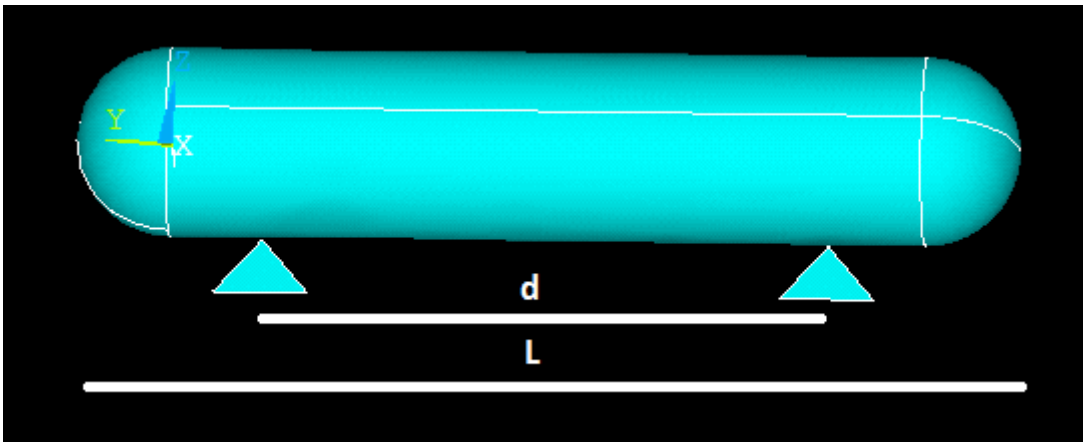
3.4.1 Static pressure stress

$$\begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{54.74º} = [Q]\cdot\begin{pmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{pmatrix} = \begin{pmatrix}92629184\\ 19870815\\ 3510100.11921\end{pmatrix}(\text{Pa}) \qquad \text{[eq.(32)]}$$

$$\begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{-54.74º} = [Q]\cdot\begin{pmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{pmatrix} = \begin{pmatrix}92629184\\ 19870815\\ -3510100.11921\end{pmatrix}(\text{Pa}) \qquad \text{[eq.(32)]}$$

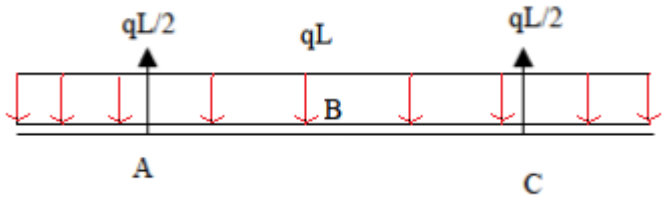
3.4.2 Study of the bending moment diagram. (induced stress)

We are going to study where is the optimal position of the supports using reference [1]:



3.5.2 Pic 1: Scheme of the deposit with the supports

This is the distribution of pressure and the reactions in the supports of our deposit



3.4.2 Pic 2: Distribution of pressure and reactions in the supports. Reference [1]

The load per unit of length will be :

$$q = \frac{(\frac{4}{3}\pi(R_{EXT}^3 - R_{INT}^3) + 2\pi R_{EXT} t L)}{L}\cdot\rho_{material}\cdot g + \frac{(\frac{4}{3}\pi R_{INT}^3 + \pi R_{INT}^2 L)}{L}\cdot\rho_{liquid}\cdot g \qquad (64)$$

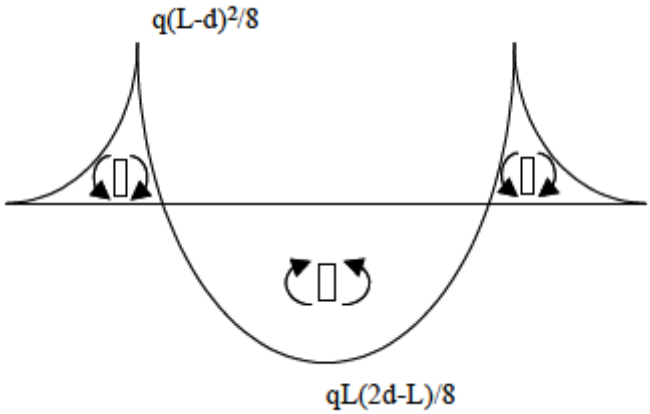
Being:

$$\rho_{liquid} = 0.559\frac{kg}{l}\cdot 1\frac{l}{dm^3}\cdot 10^3\frac{dm^3}{m^3} = 559\ \frac{kg}{m^3}$$

So , the load per unit of length will be:

$$q = 6027.772\left(\frac{N}{m}\right)$$

This is the bending momentum diagram:



3.5.2 Pic 3: Bending momentum diagram Reference [1]

The maximum momentum that must resist our deposit is:

$$\sigma = \frac{M_{max}\cdot R}{I} = \frac{M_{max}\cdot R}{\frac{\pi\left(R_{ext}^4 - R_{int}^4\right)}{4}} \rightarrow M_{max} = \frac{\sigma\cdot\frac{\pi\left(R_{ext}^4 - R_{int}^4\right)}{4}}{R} \qquad (65)$$

For the deposit will not brake must resist the two points of maximum momentum, so the " d " distance must be:

$$M_A < M_{max} \rightarrow \frac{q\cdot(L-d)^2}{8} < \frac{\sigma\cdot\frac{\pi\left(R_{ext}^4 - R_{int}^4\right)}{4}}{R} \sim d \geq L - \sqrt{\frac{2\sigma R}{\rho g}} \qquad (66)$$

$$M_B < M_{max} \rightarrow \frac{qL\cdot(2d-L)}{8} < \frac{\sigma\cdot\frac{\pi\left(R_{ext}^4 - R_{int}^4\right)}{4}}{R} \sim d \leq \frac{L}{2} + \frac{\sigma R}{\rho g L} \qquad (67)$$

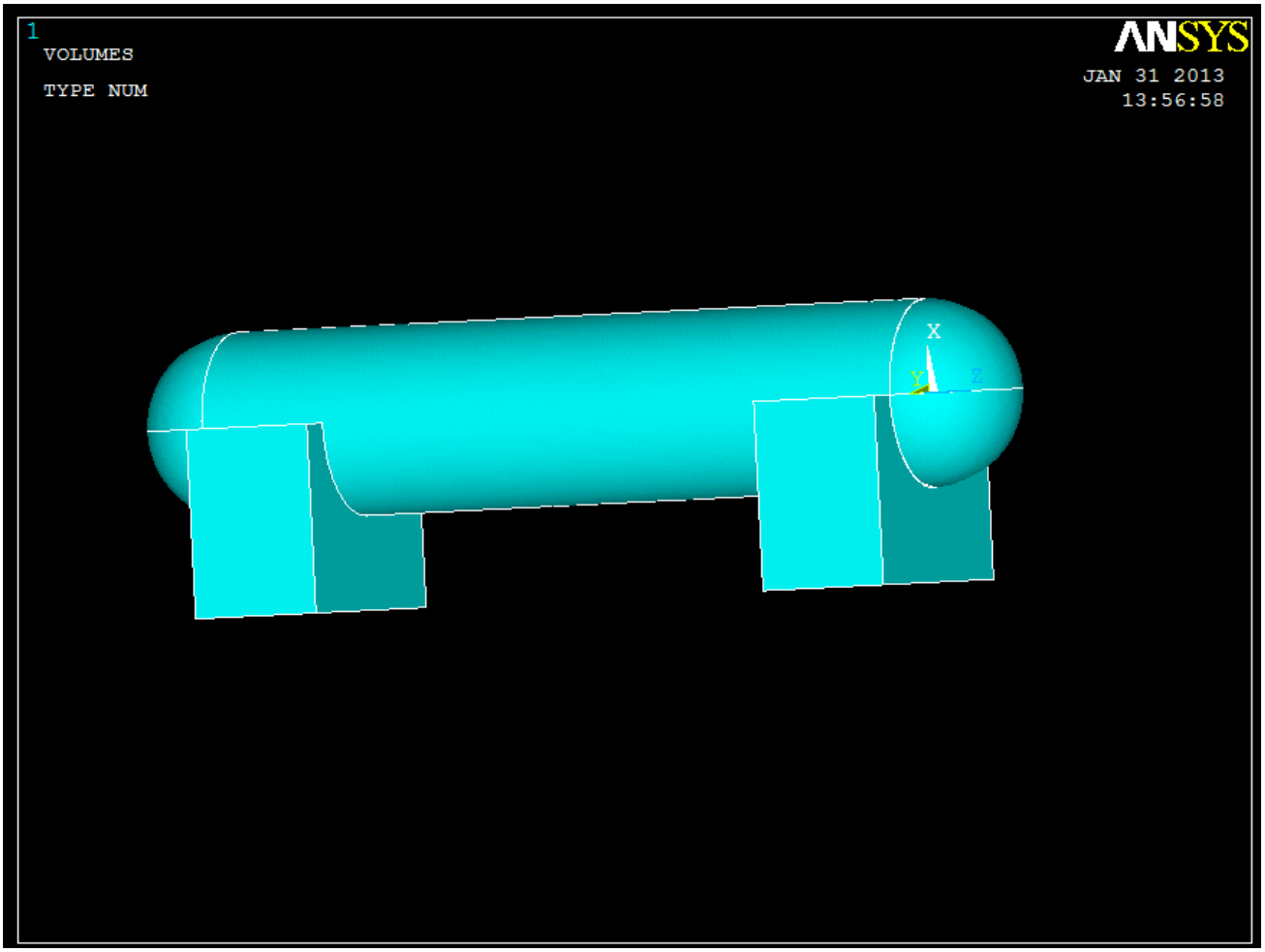
So, the distance " d " must be between:

$$\mathrm{L} - \sqrt{\frac{2\sigma_{\mathrm{Resistance}}\mathrm{R}}{\rho g}} \leq \mathrm{d} \leq \frac{\mathrm{L}}{2} + \frac{\sigma_{\mathrm{Resistance}}\mathrm{R}}{\rho g \mathrm{L}} \qquad (68)$$

This means that for the properties of our deposit we can put the support wherever we want while we keep right this equation, so using the logic we have to possibilities:

	L	d
Position 1	**5**	**3**
Position 2	**5**	**4**

I choose the position 2 because is the more equilibrate position in case of induced stresses. We will put 2 supports like that:

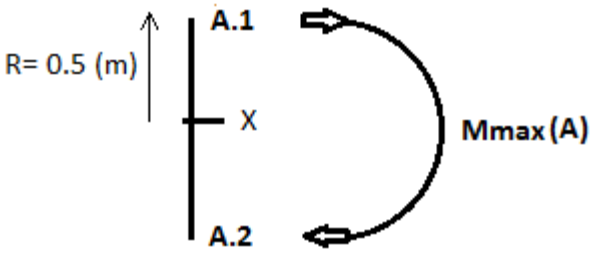


3.4.2 Pic 4: Schema of the optimal position of the supports in the deposit

Following the normative, we must establish the deposit with an inclination not above 1% for making easier and effective the emptying of water after the testing and the drainage.

The induced stresses are:

Point A

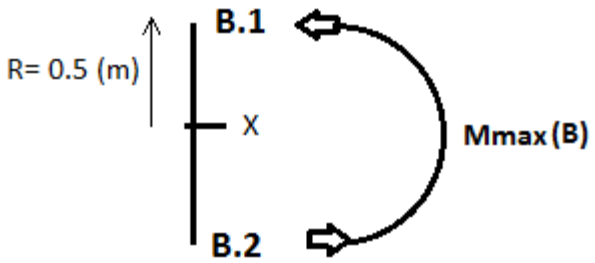


3.5.2 Pic 5: Distribution of bending induced stresses in support A .

$$\{\sigma_{A.1}\} = \begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix}_{global\ axes} = \begin{pmatrix} 0.203773 \cdot 10^6 \\ 0 \\ 0 \end{pmatrix} (Pa)$$

$$\{\sigma_{A.2}\} = \begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix}_{global\ axes} = \begin{pmatrix} -0.203773 \cdot 10^6 \\ 0 \\ 0 \end{pmatrix} (Pa)$$

Point B



3.4.2 Pic 6: Distribution of bending induced stresses in support B .

$$\{\sigma_{B.1}\} = \begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix}_{global\ axes} = \begin{pmatrix} -0.254716 \cdot 10^6 \\ 0 \\ 0 \end{pmatrix} (Pa)$$

$$\{\sigma_{B.2}\} = \begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix}_{global\ axes} = \begin{pmatrix} 0.254716 \cdot 10^6 \\ 0 \\ 0 \end{pmatrix} (Pa)$$

Change to the local axes in each sheet making the next step:

$$\begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix} = [T]\cdot\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}$$

54.74º orientation sheet

$$\{\sigma_{A.1}\} = \begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{local\ axes} = \begin{pmatrix}67909.807\\ 135863.77\\ -96054.581\end{pmatrix}(Pa)$$

$$\{\sigma_{A.2}\} = \begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{local\ axes} = \begin{pmatrix}-67909.807\\ -135863.77\\ 96054.581\end{pmatrix}(Pa)$$

$$\{\sigma_{B.1}\} = \begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{local\ axes} = \begin{pmatrix}-84887.259\\ -169829.714\\ 120068.2266\end{pmatrix}(Pa)$$

$$\{\sigma_{B.2}\} = \begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{local\ axes} = \begin{pmatrix}84887.259\\ 169829.714\\ -120068.2266\end{pmatrix}(Pa)$$

-54.74º orientation sheet

$$\{\sigma_{A.1}\} = \begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{local\ axes} = \begin{pmatrix}67909.807\\ 135863.77\\ 96054.581\end{pmatrix}((Pa)$$

$$\{\sigma_{A.2}\} = \begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{local\ axes} = \begin{pmatrix}-67909.807\\ -135863.77\\ -96054.581\end{pmatrix}(Pa)$$

$$\{\sigma_{B.1}\} = \begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{local\ axes} = \begin{pmatrix}-84887.259\\ -169829.714\\ -120068.2266\end{pmatrix}(Pa)$$

$$\{\sigma_{B.2}\} = \begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{local\ axes} = \begin{pmatrix}84887.259\\ 169829.714\\ 120068.2266\end{pmatrix}Pa)$$

3.4.3 Static study of failure criteria

We are going to use the Tsai-hill criteria(equation (45)) for knowing if our deposit resist the stresses induced by the pressure and the flexion stresses in the critic points A and B .

Remembering the stresses induced by pressure:

$$\begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{54.74º} = \begin{pmatrix}92629184\\ 19870815\\ 3510100.11921\end{pmatrix} (\text{Pa})$$

$$\begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}_{-54.74º} = \begin{pmatrix}92629184\\ 19870815\\ -3510100.11921\end{pmatrix} (\text{Pa})$$

the strength of my laminate using the paragraph 2.2.3 and 2.2.4 in this project (Reference[2]) :

	X_t **(Mpa)**	Y_t **(Mpa)**	S **(Mpa)**
Laminate	2240	39	63

And the TSAI-HILL criteria that is the **equation (47):**

$$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n}$$

54.74º orientation sheet

A.1)

$$\{\sigma_{total}\}_{A.1} = \{\sigma_{pressure}\}_{local\ axes} + \{\sigma_{flexion}\}_{local\ axes} = \begin{pmatrix}92697093.807\\ 20006678.77\\ 3414045.53821\end{pmatrix} (Pa)$$

$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n}$ → **n= 3.58958**

This means that my deposit resist the stresses in this point with a security coefficient the 3.6 .

A.2)

$$\{\sigma_{total}\}_{A.1} = \{\sigma_{pressure}\}_{local\ axes} + \{\sigma_{flexion}\}_{local\ axes} = \begin{pmatrix}92561274.193\\ 19734951.23\\ 3606154.691\end{pmatrix} (Pa)$$

$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n}$ → **n= 3.76482**

This means that my deposit resist the stresses in this point with a security coefficient the 3.76 .

B.1)

$$\{\sigma_{total}\}_{B.1} = \{\sigma_{pressure}\}_{local\ axes} + \{\sigma_{flexion}\}_{local\ axes} = \begin{pmatrix} 92544296.741 \\ 19700985.286 \\ 3630168.3366 \end{pmatrix} (Pa)$$

$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n}$ → **n= 3.799**

This means that my deposit resist the stresses in this point with a security coefficient the 3.8 .

B.2)

$$\{\sigma_{total}\}_{B.1} = \{\sigma_{pressure}\}_{local\ axes} + \{\sigma_{flexion}\}_{local\ axes} = \begin{pmatrix} 92714071.259 \\ 20040644.714 \\ 3390031.8834 \end{pmatrix} (Pa)$$

$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n}$ → **n= 3.4757**

This means that my deposit resist the stresses in this point with a security coefficient the 3.5 .

<u>-54.74º orientation sheet</u>

A.1) $\{\sigma_{total}\}_{A.1} = \{\sigma_{pressure}\}_{local\ axes} + \{\sigma_{flexion}\}_{local\ axes} = \begin{pmatrix} 92697093.807 \\ 20006678.77 \\ -3414045.53821 \end{pmatrix} (Pa)$

$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n}$ → **n= 3.50624**

This means that my deposit resist the stresses in this point with a security coefficient the 3.5 .

A.2)

$$\{\sigma_{total}\}_{A.1} = \{\sigma_{pressure}\}_{local\ axes} + \{\sigma_{flexion}\}_{local\ axes} = \begin{pmatrix} 92561274.193 \\ 19734951.23 \\ -3606154.691 \end{pmatrix} (Pa)$$

$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n}$ → **n= 3.76482**

This means that my deposit resist the stresses in this point with a security coefficient the 3.76 .

B.1)

$$\{\sigma_{total}\}_{B.1} = \{\sigma_{pressure}\}_{local\ axes} + \{\sigma_{flexion}\}_{local\ axes} = \begin{pmatrix} 92544296.741 \\ 19700985.286 \\ -3630168.3366 \end{pmatrix} (Pa)$$

$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n}$ → **n= 3.799**

This means that my deposit resist the stresses in this point with a security coefficient the 3.8 .

B.2)

$$\{\sigma_{total}\}_{B.1} = \{\sigma_{pressure}\}_{local\ axes} + \{\sigma_{flexion}\}_{local\ axes} = \begin{pmatrix} 92714071.259 \\ 20040644.714 \\ -3390031.8834 \end{pmatrix} (Pa)$$

$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < \frac{1}{n}$ → **n= 3.4757**

This means that my deposit resist the stresses in this point with a security coefficient the 3.5 .

3.4.4 Conclusion

How we can see, the deposit resist all the stresses in the critic points with a security coefficient upper than 3.Now we are going to study the deposit with a program of finite elements like ANSYS program.

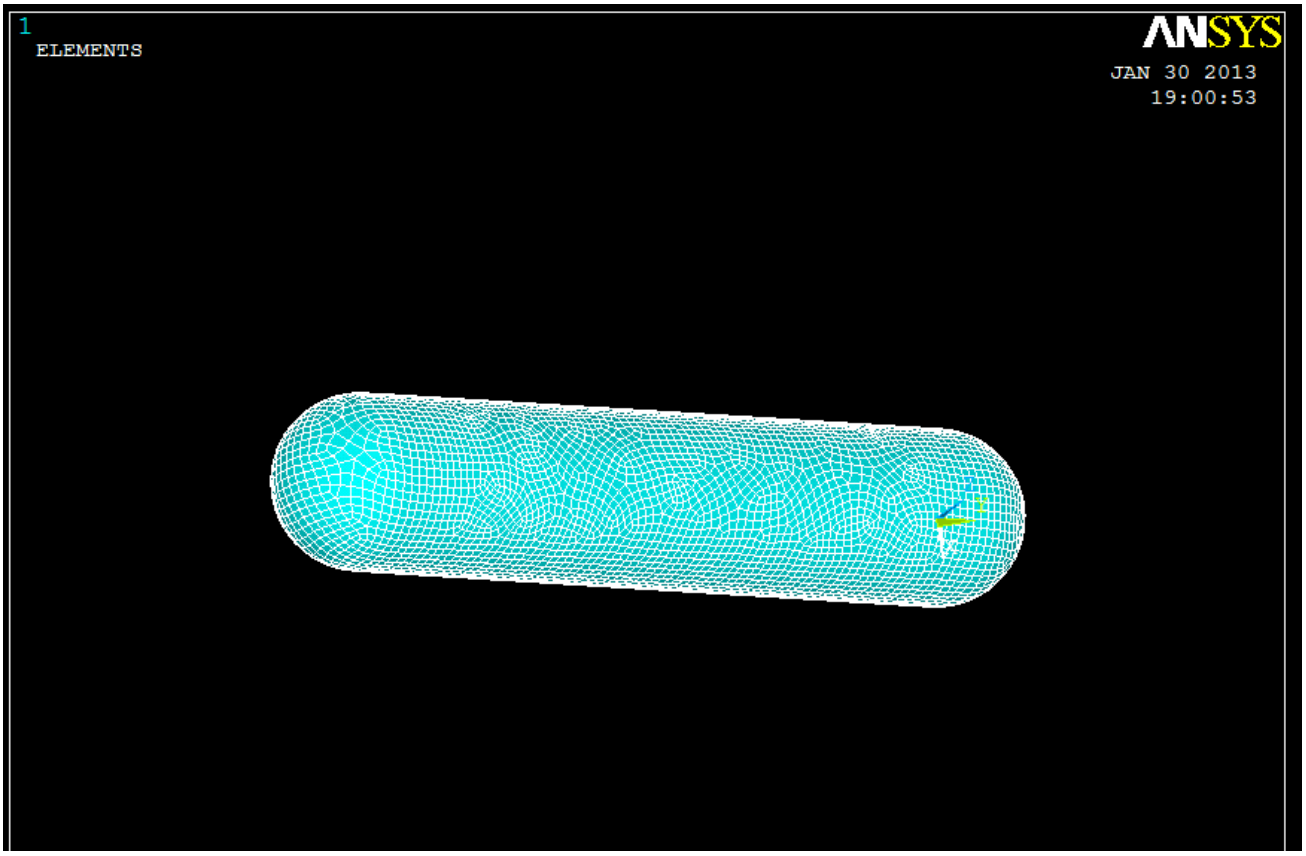
3.4.5 Study of the deposit in FE with ANSYS program

In this paragraph we are going to study of the deposit with a FE program called ANSYS. For making it we used the references [3],[4] and [5].

The first step is to design the deposit and mesh it with the element SHELL63.We choose this element because for this kind of study is efficient and fast in calculus.

After that , we will put the pressure of 30 bar inside, and we will make the ANSYS to study the structural analysis for our deposit.

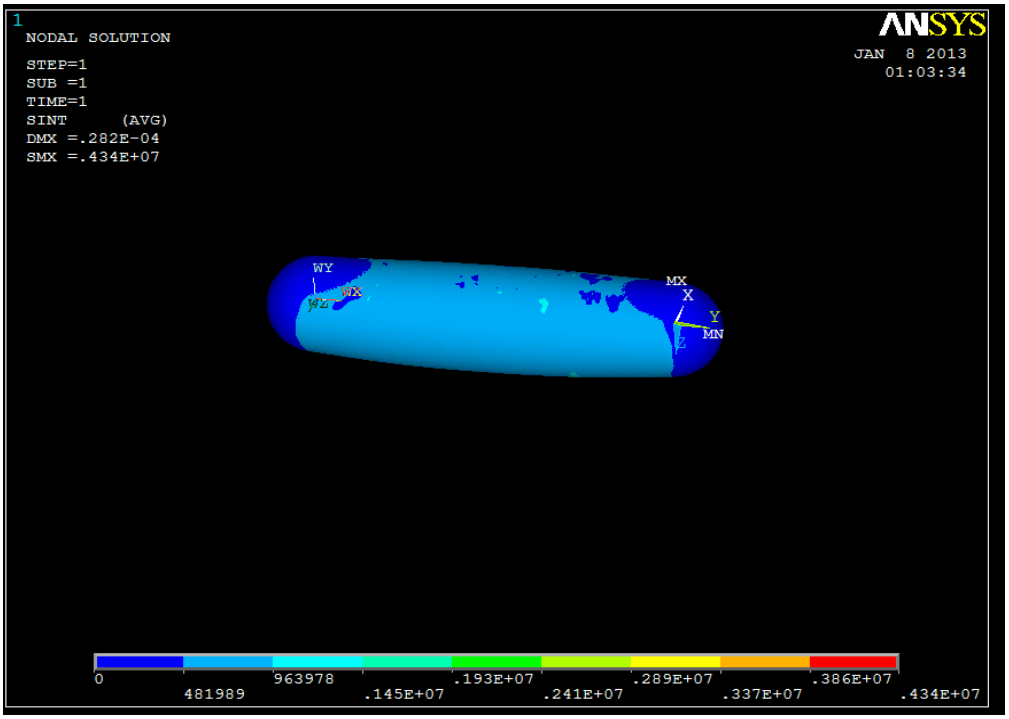
Here we can see our meshed deposit:



3.4.5 Pic 1: Meshed deposit with the FE SHELL63 in ANSYS

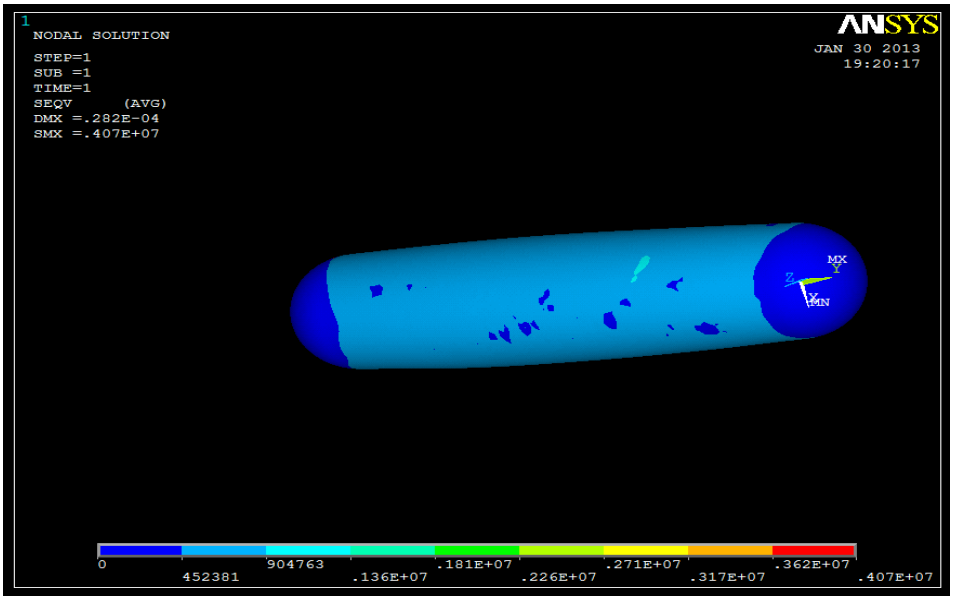
NOTE: In the study, we must interpret the images with the units that the ANSYS has measured. Red don't need to mean wrong design. Read the annotations below the pictures.

NODAL SOLUTION – STRESS INTENSITY



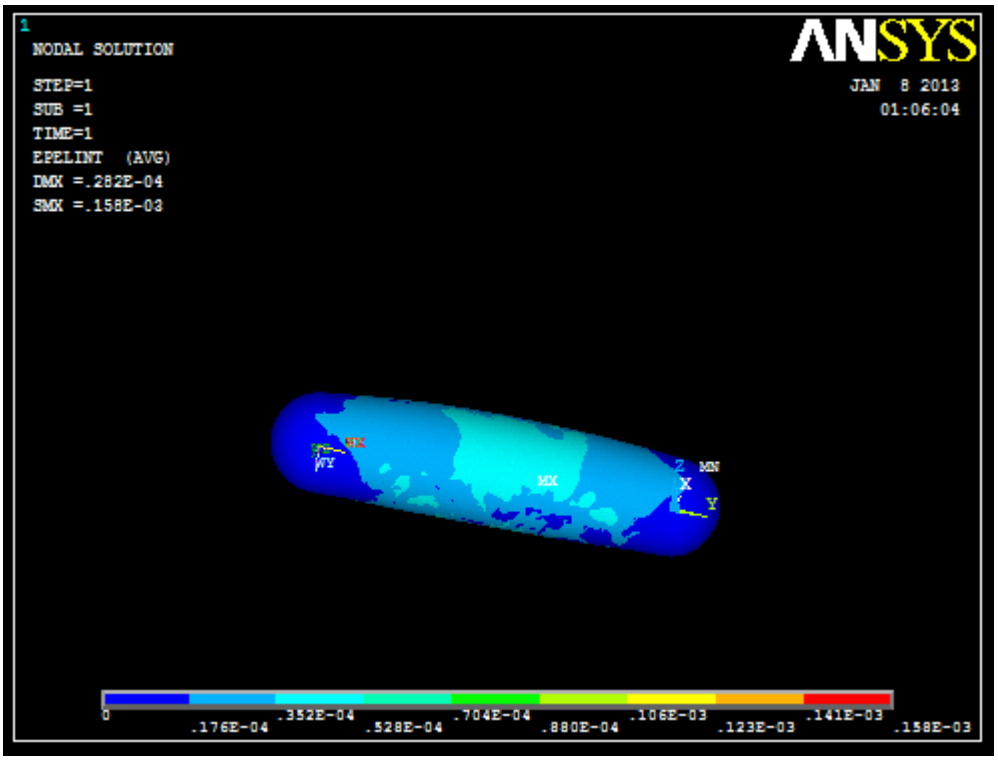
3.4.5 Pic 2: ANSYS analysis of the stress intensity in the deposit.

In 3.4.5 Pic 2 and Pic 3 we can see the study in Finite elements in ANSYS of our deposit. How we can see, the worse points that we have in the ANSYS analysis have 963978 Pa , so similar with the values obtained in the theory calculus. We also can see that our deposit is good designed , with a correct thickness and size for supporting the pressure, without dangerous points where the deposit could brake.



3.4.5 Pic 3: ANSYS analysis of the stress intensity in the deposit.

NODAL SOLUTION – ELASTIC STRAIN INTENSITY

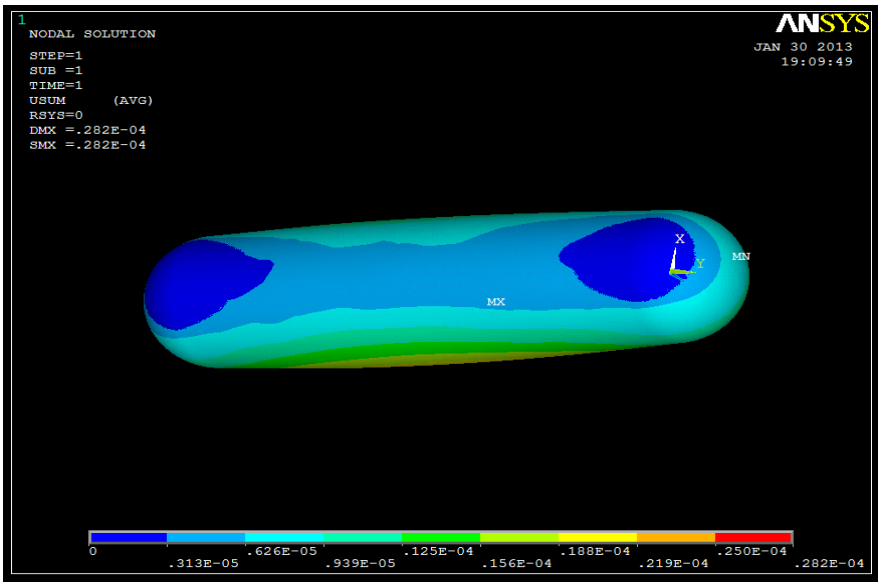


3.4.5 Pic 4: ANSYS analysis of the strain intensity in the deposit.

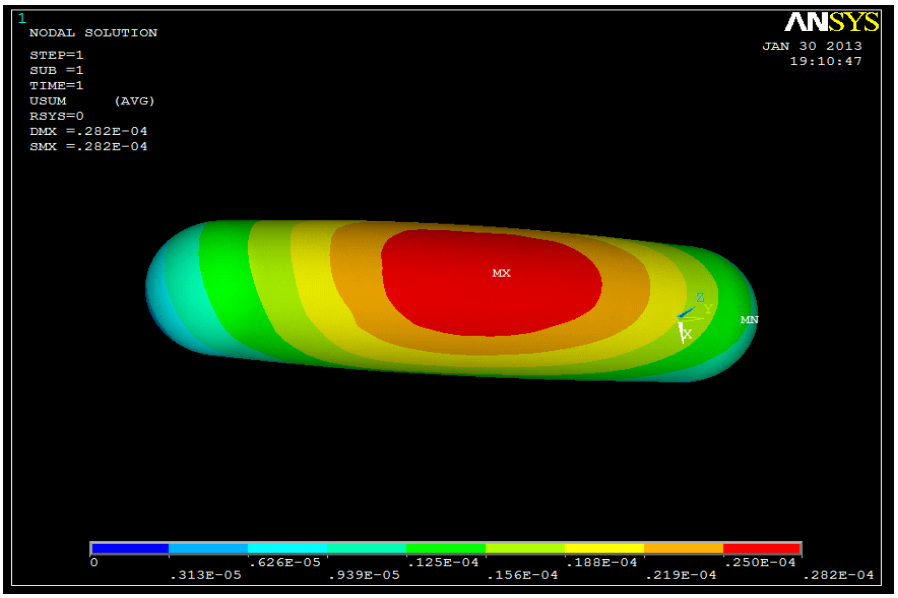
In 3.4.5 Pic 5 we can see the strain analysis of our deposit during the service. We can see that the maximum areas of deformation have deformations of approximately 0.325E-4, this means that the strain of our deposit is less than the 0.00325% that is an insignificant deformation. We have to take in count that we are working with 30 bar of pressure with a coefficient of security of 3, so in service it will be so much more less the deformation.

We also can see that the areas with higher deformation are in the middle of the deposit, areas that are far of the supports, standing floating in air , supported by the supports in the extremes. In the hemispherical caps we can see that the stress and the strain is so less, this is because in this shapes is better than the cylindrical shape for supporting stresses and strains.

DOF SOLUTION: DISPLACEMENT VECTOR SUM



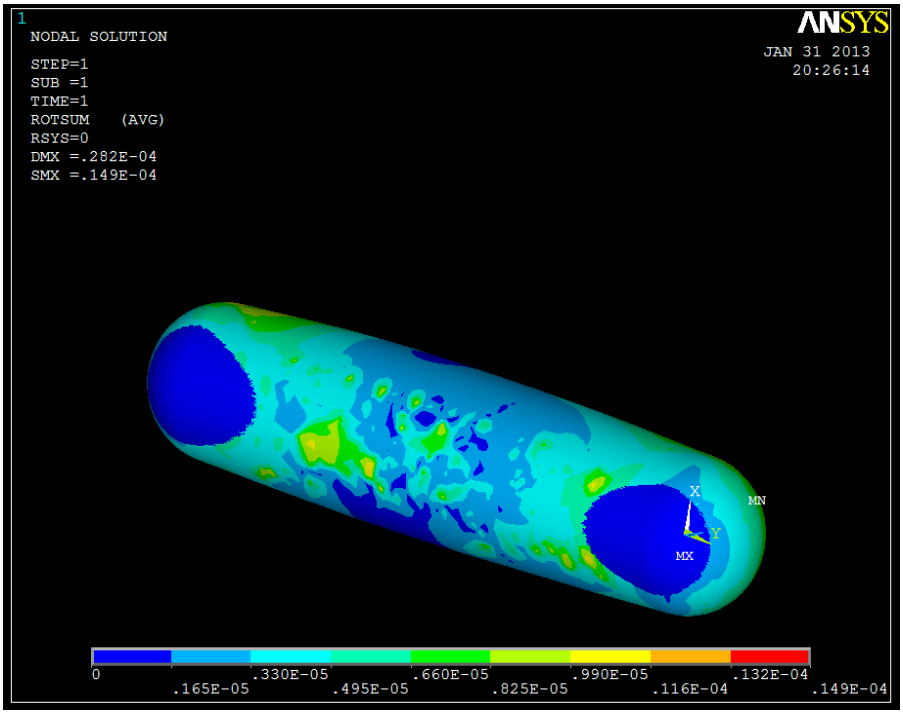
3.4.5 Pic 5: ANSYS analysis of the displacement in the upper part of the deposit.



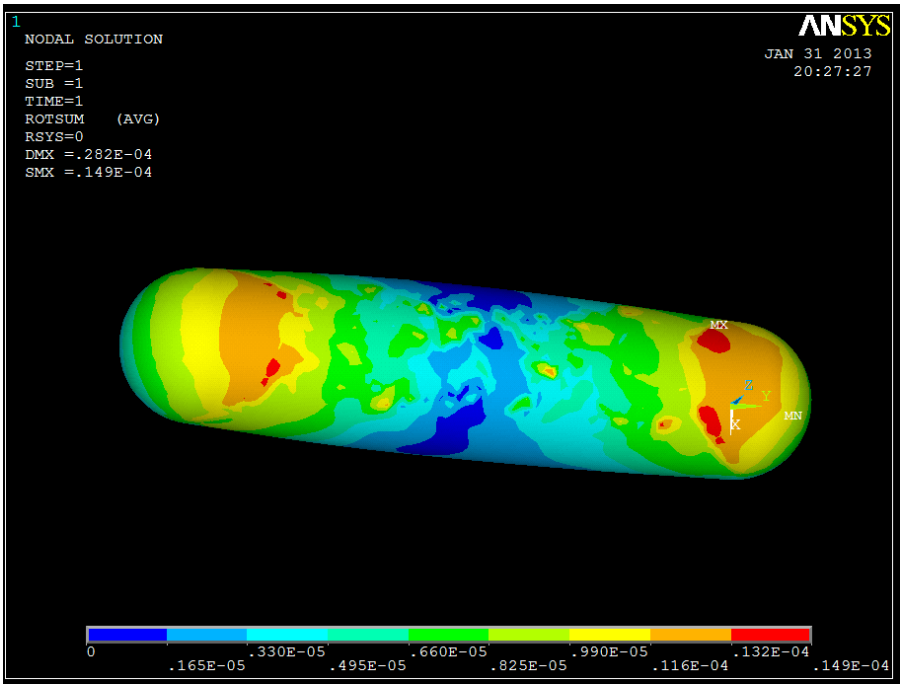
3.4.5 Pic 6: ANSYS analysis of the displacement in the lower part of the deposit.

In 3.4.5 Pic 5 and Pic 6 we can see that the worse part of the deposit, that is below the middle part, suffers a displacement of 0.25E-4 meters, that is a displacement of 0.025 mm. This displacement is completely insignificant and the stability of our deposit is secure.

DOF SOLUTION: ROTATION VECTOR SUM



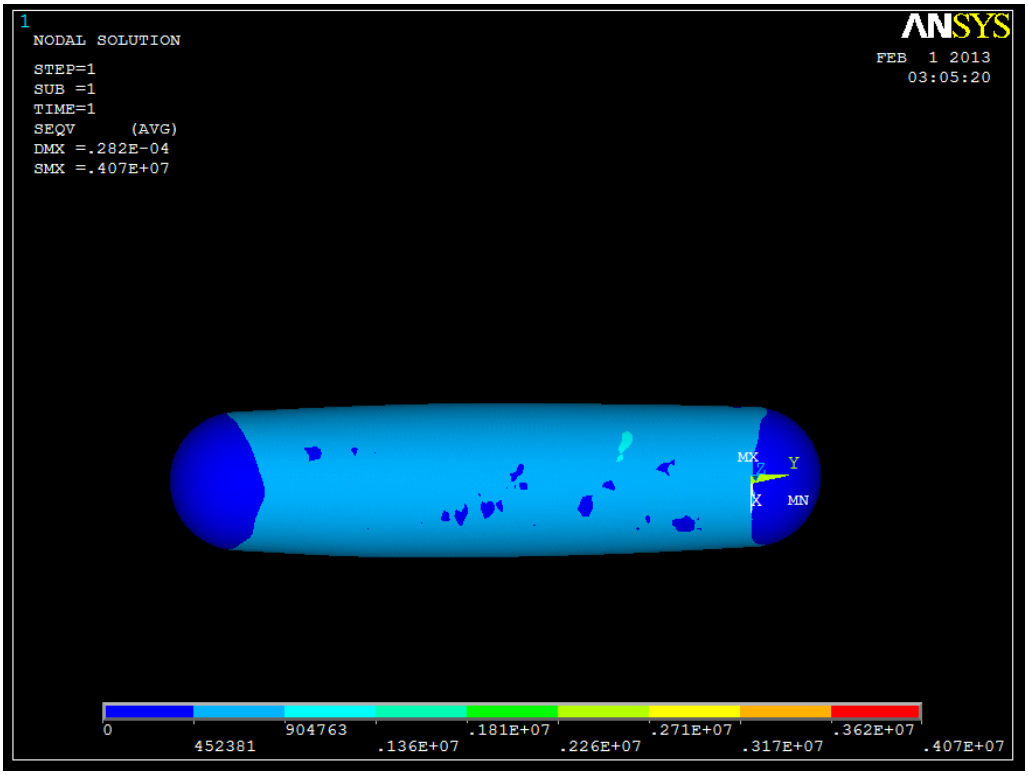
3.4.5 Pic 7: ANSYS analysis of the rotation in the upper part of the deposit.



3.4.5 Pic 7: ANSYS analysis of the rotation in the lower part of the deposit.

In the pictures 3.4.5 Pic 6 and Pic 7 we can see that the rotation induced in the points near of the supports and in the lower part because of the bending moment only produce a rotation of 0.132E-4 degrees, that is an insignificant rotation.

VON MISSES ANALYSIS



3.4.5 Pic 8: ANSYS analysis of the Von Misses Stresses in the lower part of the deposit.

In the 3.4.5 Pic 8 we can see that making the analysis of Von Misses in ANSYS, there is no critical points where the deposit can fail in stability or plasticating.

3.5 Dynamic analysis.

3.5.1 Thermal analysis. Thermal analysis with ANSYS

For saving the LGP we know that if there is an little increase of temperature, there will be a big increase of pressure. We also knows that the flammable point of LGP is 400ºC , and it must be with up to 15% of air in the mix, following the reference [7].

In the next table we can see how varies the pressure in function of the temperature for the propane:

TEMPERATURA (°C)	PRESION ABSOLUTA bar	DENSIDAD LIQUIDO Kgr/m3	DENSIDAD V APOR kgr/m3	ENTALPIA LIQUIDO Kj/Kg	ENTALPIA VAPOR kj/kg
40.00	13.69	467.3	30.21	207.9	514.4
41.00	14.01	465.5	30.97	210.8	515.2
42.00	14.33	463.7	31.75	213.8	516.0
43.00	14.66	461.8	32.55	216.7	516.8
44.00	15.00	460.0	33.37	219.7	517.6
45.00	15.34	458.1	34.20	222.7	518.4
46.00	15.69	456.2	35.06	225.7	519.1
47.00	16.04	454.3	35.94	228.7	519.9
48.00	16.40	452.4	36.84	231.7	520.6
49.00	16.76	450.4	37.76	234.8	521.3
50.00	17.13	448.4	38.71	237.8	522.0
51.00	17.50	446.4	39.67	240.9	522.7
52.00	17.89	444.4	40.67	244.0	523.4
53.00	18.27	442.4	41.69	247.1	524.0
54.00	18.67	440.3	42.73	250.3	524.6
55.00	19.07	438.2	43.81	253.4	525.2
56.00	19.47	436.1	44.91	256.6	525.8
57.00	19.89	433.9	46.04	259.8	526.4
58.00	20.30	431.7	47.20	263.0	526.9
59.00	20.73	429.5	48.39	266.2	527.4
60.00	21.16	427.3	49.62	269.5	527.9

3.5.1 Pic 1: Schema of the variation of pressure – temperature for propane. Reference [17]

The LGP is saved is saved between 40º - 60º for 14 – 21 bar of pressure respectively following the reference [7]. We are going to calculate an insulator for the days that the radiation of the sun can increase the temperature in the deposit. At the first time , if the temperature decrease is not a problem for saving the LGP.

The first step is to present the situation and the problem:

- We must design an insulator that make be constant the temperature in the LGP gas/liquid into the deposit, so the best days for avoiding this situation would be in summer, where the sun radiates with so much strength.

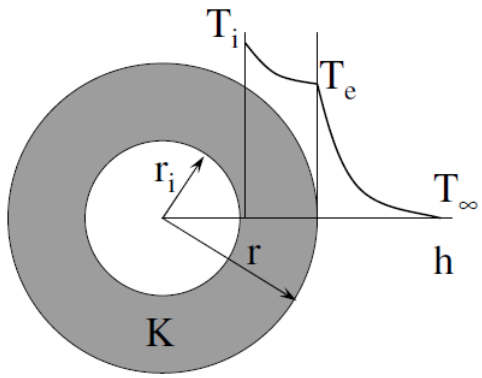
- We will design the insulator for avoid the entrance of heat into the deposit.

- We will consider the maximum temperature of service of the LGP (60 ºC at 21 bar)

- We will consider a extremely warm day in summer with 40 º C and that the radiation of the sun produce a temperature of 85ºC in the surface of the deposit. The insulator must insulate good for this surface temperature.

- We will design the insulator for avoid the flammable point in case of disaster with too much high temperatures near of the deposit. So the insulator temperature range must admit 400ºC.

- Also the insulator will avoid huge dilatations or contractions in the main structure of the deposit for variations of temperature or large periods of times in critical temperatures , keeping the deposit in a approximately constant temperature.



$$R_t = \frac{\ln(\frac{r}{r_i})}{2\pi LK} + \frac{1}{2\pi Lh} \quad (69)$$

3.5.1 Pic 1: Schema of insulator over the cylinder part of the deposit and the Thermal resistances of conduction and convection. Reference [20]

Calculating the critical radius for the isolator in the cylindrical surface using reference [20] and the 3.5.1 Pic 1:

$$\frac{dR_r}{dr} = 0 \rightarrow \frac{1}{2\pi LK}\left\{\frac{\frac{1}{r_i}}{\frac{r_{crit}}{r_i}} - \frac{K}{h}\cdot\frac{1}{r_{crit}^2}\right\} = 0$$

$$\boldsymbol{r_{crit}} = \frac{\boldsymbol{K}}{\boldsymbol{h}}\ (\text{m}) \qquad (70)$$

Making the same procedure for the spherical caps we will have:

$$\boldsymbol{r_{crit}} = \frac{\boldsymbol{2\cdot K}}{\boldsymbol{h}}\ (\text{m}) \qquad (71)$$

The critical radius will be bigger in the spherical surface.

Now, taking in count the convection coefficient for the air at 40ºC in two conditions:

Air (without forced convection, without airflow)	$h_e = 30\frac{W}{m^2K}$
Air (with forced convection, with airflow)	$h_e = 130\frac{W}{m^2K}$

The worse situation will be when the deposit will not can loose all the heat that is receiving, so we will choose the convection coefficient for the air without airflow.

Now, studying different types of insulators (References [13] and [14]) taking in count the conditions for the design mentioned before, we choose the next insulator of 3.5.1 Pic 2, because is light, cheap and works so good with our conditions:

	GLASS MINERAL WOOL			
1	**Density (and range, if applicable)**			10 to 80 kg/m³
2	**Thermal Conductivity**			
		Thermal conductivity (W/mK) at density indicated below		
	Mean temp °C	16 kg/m³	48 kg/m³	80 kg/m³
	-20	0,031	0,028	0,028
	10	0,037	0,030	0,031
	20	0,040	0,032	0,032
	50	0,047	0,035	0,035
	100	0,065	0,044	0,042
3	**Service Temperature range**			- 200 to 450°C
4	**Reaction to Fire Characteristics**			
	a. Combustibility to BS476 part 4			Non Combustible
	b. Surface spread to flame to BS476 part 7			
	Insulant (if appropriate)			Class 1
	Composite finish (if appropriate)			Class 1
	Foil faced products (if appropriate)			Class 1
	c. Building Regulations			
	Insulate (if appropriate)			Class 0
	Composite finish (if appropriate)			Class 0
	Foil faced products (if appropriate)			Class 0
5	**Water Vapour Transmission**			
	Insulant (if appropriate)			N/a
	Composite finish/foil faced product (if appropriate)			0,001g/(s. MN)
6	**Mechanical Properties**			
	a. Compressive strength			1 to 8 kN/m² at 5% deformation
	b. Flexural strength			N/a
	c. Tensile strength			N/a
7	**Thickness Range**			Available from 5 to 150mm
8	**Forms available**			Blown Fibre, Pipe Sections, Rolls, Slabs

TYPICAL USES AND APPLICATIONS

Glass mineral wool is available in a wide range of forms ranging from flexible rolls to rigid slabs and preformed pipe sections. It is particularly suitable for thermal and acoustic applications in the H & V sector and is also used as both a thermal and an acoustic insulation in transport, shipping, building and industrial applications.

3.5.1 Pic 2 : Insulator for the deposit. Reference [14]

So, choosing a conduction coefficient of the insulator in the 3.5.1 Pic 2:

$$k_{insulator} = 0.038 \frac{W}{m\,K}$$

The critical radius following reference [20], that is the thickness of insulator, will be :

$$\boldsymbol{r_{crit}} = \frac{\boldsymbol{2 \cdot K}}{\boldsymbol{h}} = 2.53 \cdot 10^{-3}\ (m) = 2.53\ (mm) \approx 3(mm)$$

Taking in count a security coefficient of 2 , the thickness of our insulator will be **6 mm**.

Now, we are going to make an thermic study with ANSYS, so we need to calculate the conductivity coefficient of our composite, for that, following the reference [14] for equations (72) and (73):

$$K_1 = K_2 = V_f \cdot K_f + V_m \cdot K_m \qquad (72)$$

$$K_{transversal} = K_m + \frac{K_m(K_f - K_m)V_f}{K_m + \frac{V_m(K_f - K_m)}{2}} \qquad (73)$$

So taking in count the following properties got it form reference [13]:

Thermic conductivity (EPOXY)	$0.4\,\frac{W}{m\,K}$
Thermic conductivity (Glass fiber)	$0.04\,\frac{W}{m\,K}$

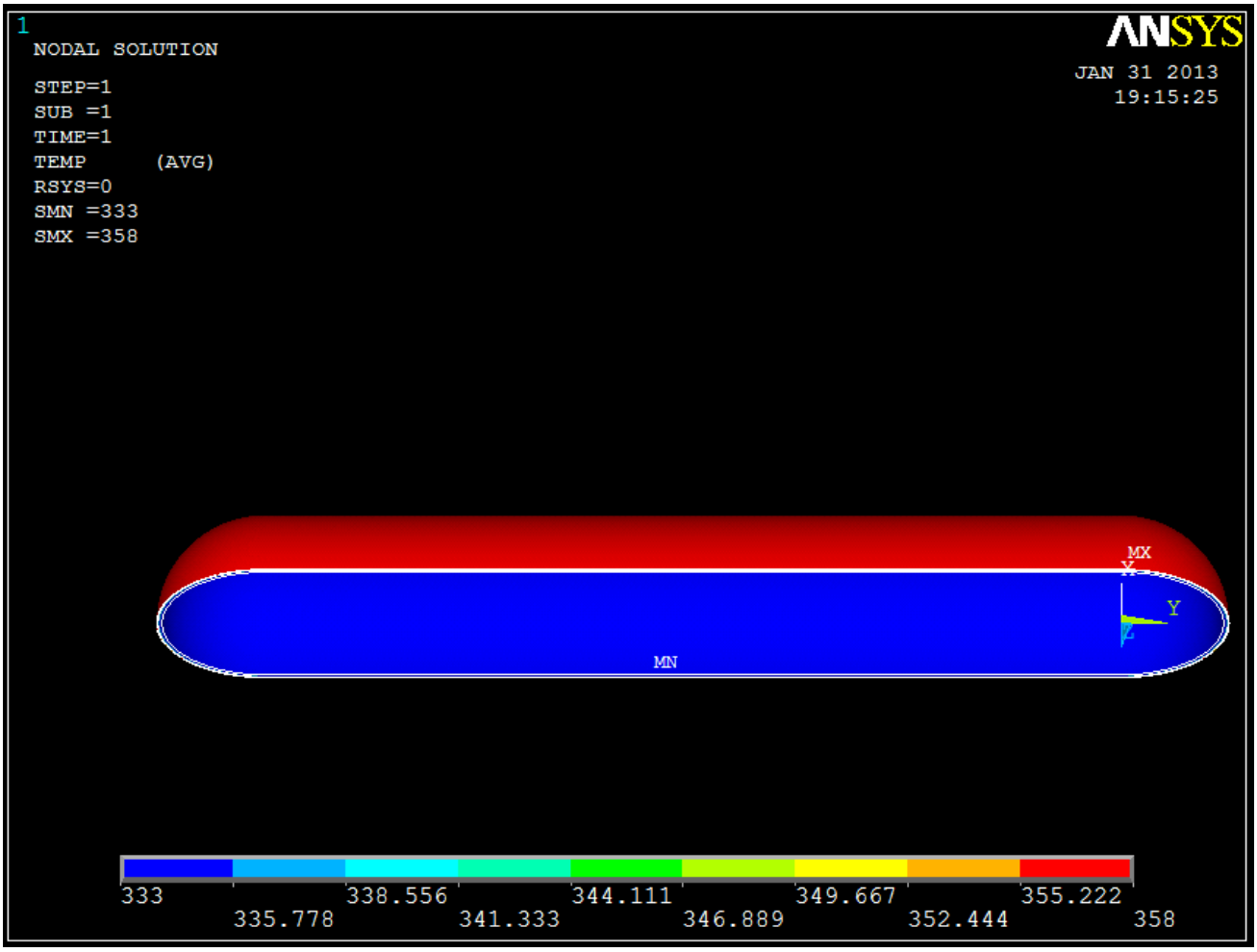
So, with a 70% of fibers, the thermic conductivity of our composite will be:

$$K_1 = K_2 = V_f \cdot K_f + V_m \cdot K_m = 0.148\ \frac{W}{m\,K}$$

$$K_{transversal} = K_m + \frac{K_m(K_f - K_m)V_f}{K_m + \frac{V_m(K_f - K_m)}{2}} = 0.10867\,\frac{W}{m\,K}$$

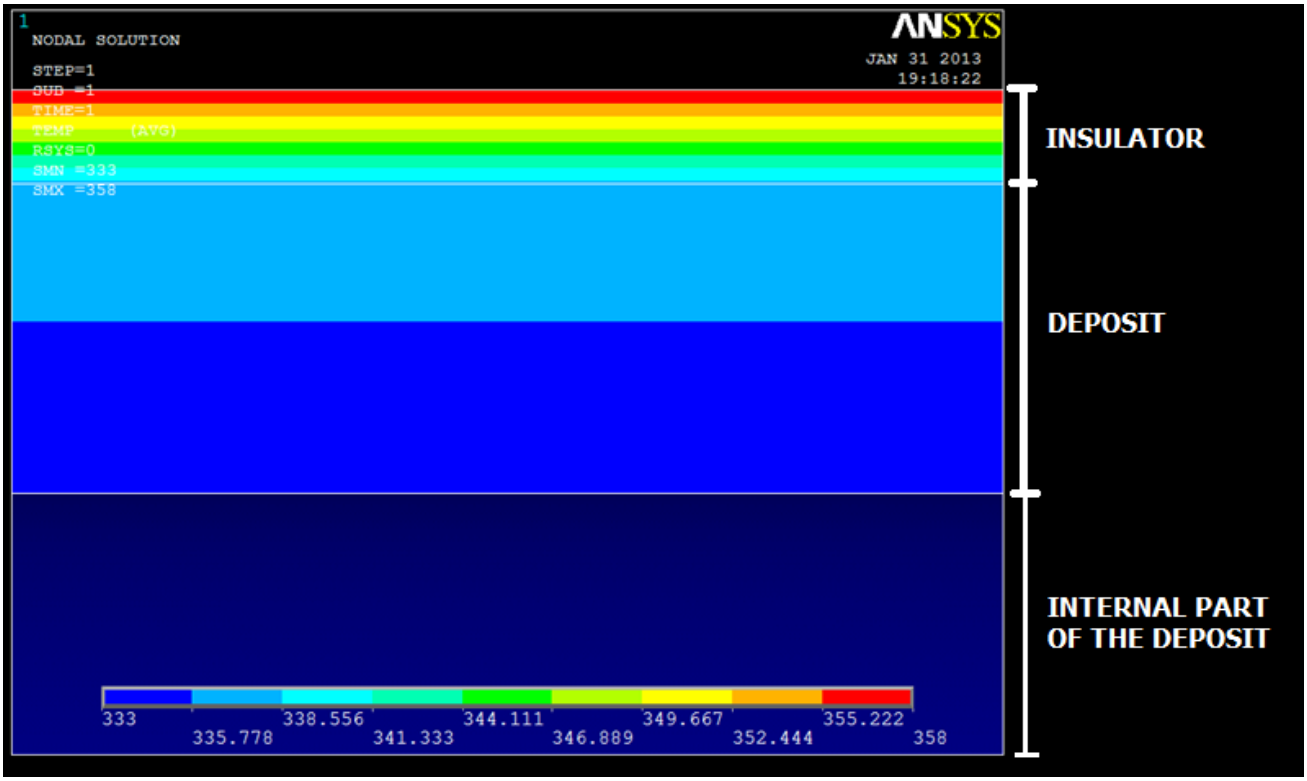
The references that we used in this paragraph are **references [13], [14] and [20]**.

Now, making the thermic analysis with ANSYS:



3.5.1 Pic 2: Representation of the section of the deposit with surface temperatures in ºKelvin.

In the picture 3.5.1 Pic 2 we have the section of the deposit, with the external surface at 358 ºK and the internal surface at 333ºK how we said in the conditions of study.



3.5.1 Pic 3: Gradient of temperatures in the section of the thickness of the deposit in ºKelvin.

In the picture 3.5.1 Pic 3 we can see the gradient of temperature in the section of the thickness, for realizing how works the insulator and seeing how is this variation of temperature.

We can see that we have a big gradient of temperature in the thickness of the insulator. This means that across this section the heat flux is so small, because the difference of temperature between the upper surface and lower is like 30ºK, keeping the upper surface of the deposit at 338ºK and the internal temperature of the deposit at 333ºK (60ºC) , how we wanted in the design.

Take in count, that if the insulator will not accomplish his function, we would see that there would not be almost variation of temperature in the thickness of the insulator, what would mean that the heat flux have cross the section, and the temperature into the deposit would be higher.

For the case that the temperature is lower in the external ambient of the deposit we will not make an study, because this conditions is good for our deposit, because when the temperature increase into the deposit, the pressure will decrease also, and this will better for the stability of our deposit.

3.5.2 Modal analysis of the deposit with ANSYS. Frequency of vibrations

In this paragraph we are going to make the modal analysis of our deposit following the references [3],[4] and [5] . The explication for doing it is that we must know at what frequencies our deposit can start vibrating and produce a failure due to de vibration. This is a really important study in areas where there is a lot of seismic activity or where the different types of wind produce critical vibrations in the structure.

In case that the deposit would be established in an area where can get the resonance frequency, we will must establish an insulating system for avoiding this frequencies of vibration in the structure. This insulating system goes from base/floor insulating and vibration control system passive or active compounds of different types of dumpers and mass mechanism (Data from Reference [8]).

For doing it we are going to use ANSYS . We will find 25 modes of vibration of our deposit between 0 Hz and 1000 Hz, and we will present one example of how our deposit can deform with this frequency of vibration.

Here we have the different modes of vibration:

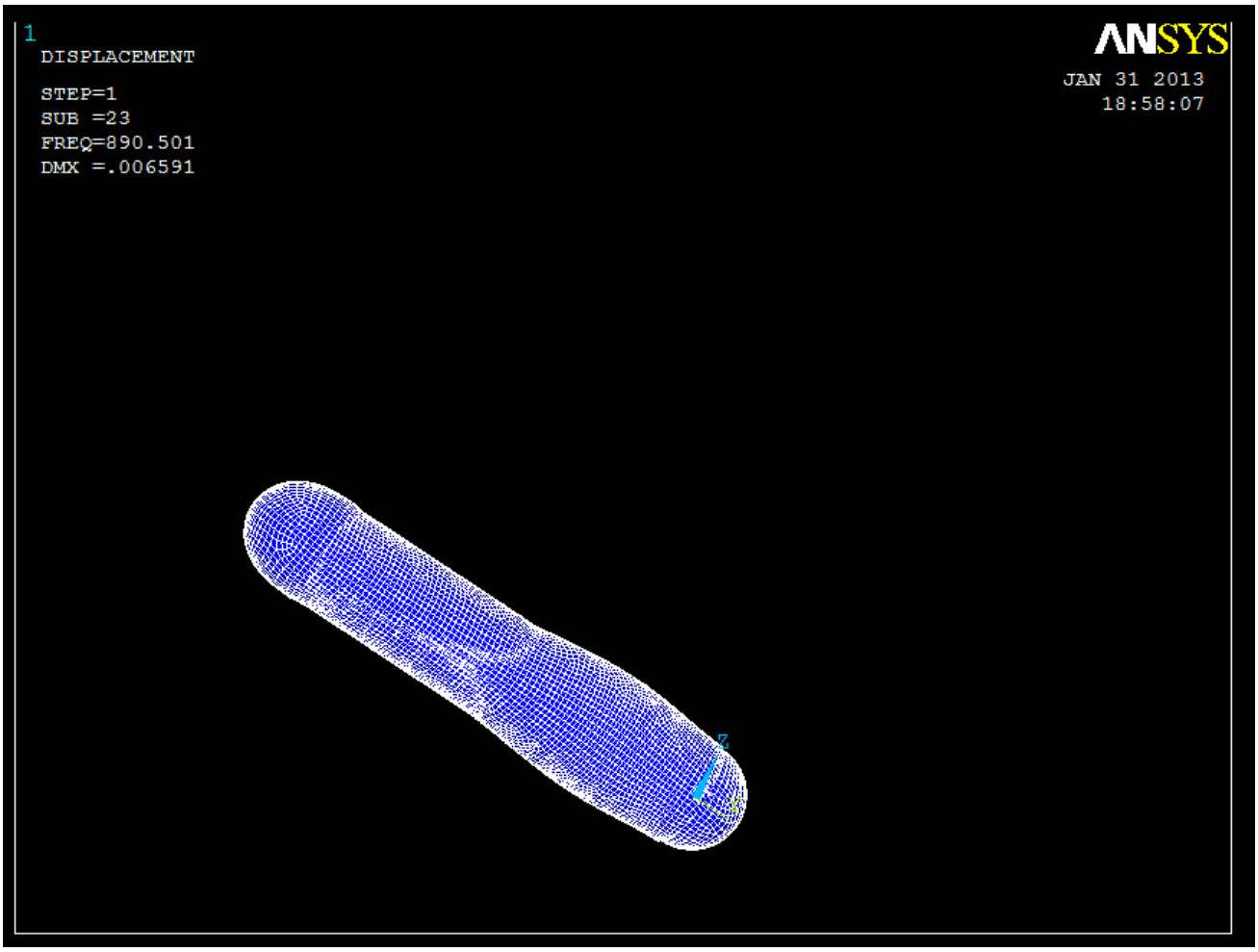
Results File: PROYECTOFINALMARTI@

Available Data Sets:

Set	Frequency	Load Step	Substep	Cumulative
1	0.0000	1	1	1
2	3.87624E-04	1	2	2
3	7.26182E-04	1	3	3
4	0.16954	1	4	4
5	0.18393	1	5	5
6	0.76293	1	6	6
7	172.23	1	7	7
8	248.55	1	8	8
9	267.07	1	9	9
10	293.73	1	10	10
11	316.84	1	11	11
12	375.94	1	12	12
13	517.80	1	13	13
14	561.74	1	14	14
15	598.51	1	15	15
16	610.25	1	16	16
17	626.20	1	17	17
18	650.34	1	18	18
19	661.33	1	19	19
20	698.07	1	20	20
21	705.86	1	21	21
22	773.87	1	22	22
23	890.50	1	23	23
24	963.35	1	24	24
25	995.54	1	25	25

3.5.2 Pic 1 : List of modes of vibration of our deposit between 0 Hz and 1000 Hz

So, for example, studying the mode 23, that have the frequency of 895.5 Hz , ANSYS show us that this could be the deformation of the deposit due to this vibration frequency:



3.5.2 Pic 1: Deformation of the deposit due to 850.5 Hz vibration frequency

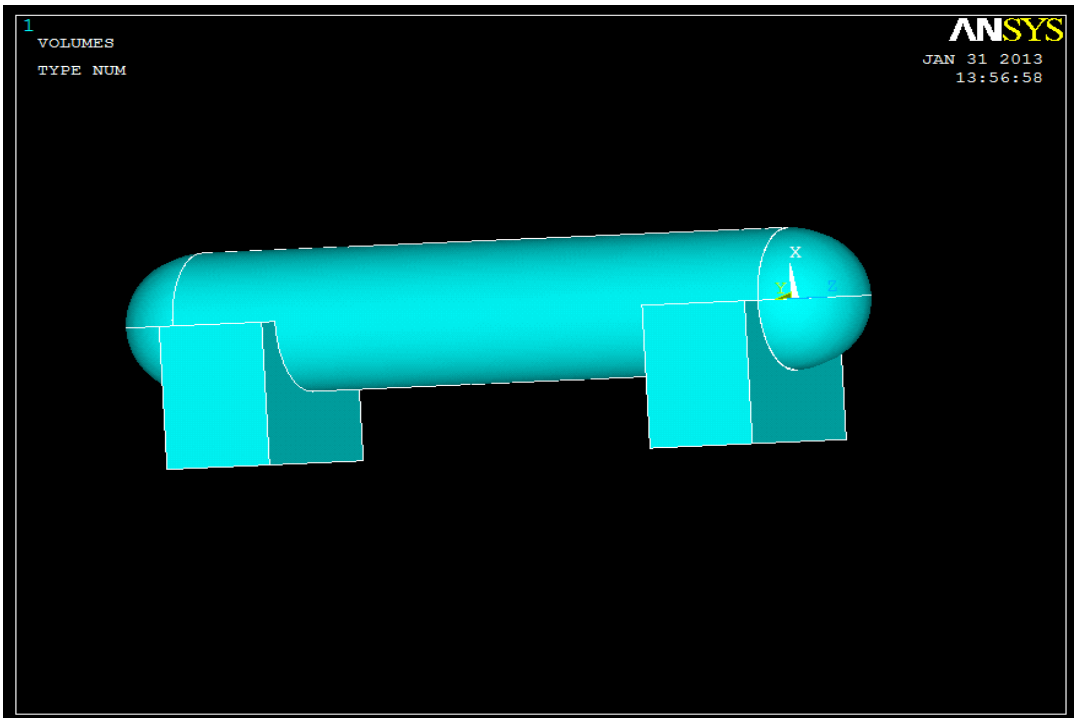
We can see in the picture 3.5.2 Pic 1 that the middle part of the deposit would contract and the other would bulge, and the caps also would bulge because of the vibration. We have to take in count that this deformations could not be too big, but we must take care with that because could produce the failure of the deposit.

3.6 Study of the supports of the deposit

Here we are going to present one of the possible models for supporting the deposit. We have to take in count, that at the first time, we designed the deposit with an insulator with the idea of avoid the mean dilatations due a big and faster variations of temperature.

Even taking in count this point, the normative says that we must let free one of the degrees of freedom for letting the deposit dilate in case that, even with the insulator in our case, the temperature vary and produce dilatations. We will let free the longitudinal grade of liberty.

Now we present the support:

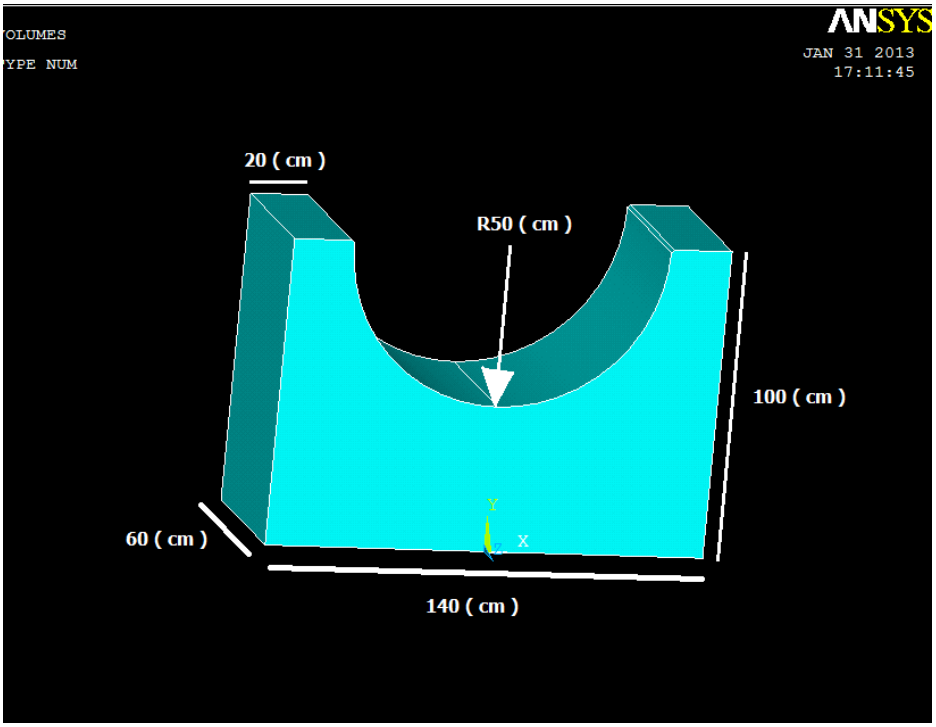


3.6 Pic 1: Schema of the deposit with the supports

We will choose steel how material for manufacturing the supports for the deposit.

Following the normative of steel in reference [12] and [19] for the constructions, we have the following characteristics for the steel S275 JR :

- Modulus of Elasticity E 210.00 N/mm^2
- Shear modulus G 81.00 N/mm^2
- Poisson coefficient ν 0.3
- Coefficient of thermal expansion α $1.2 \cdot 10^{-5}\ (^{o}C)^{-1}$
- Density ρ 7850 kg/m^3



3.6 Pic 2: Schema and main dimensions of the support

In the process of manufacturing of the dimensions we must take in count the tolerances, the screws and the nuts for the establishment of the deposit in the supports.

Now we are going to make the mechanical study of the supports with the ANSYS.

The supports must support the deposit in the moment of maximum load, so they must support:

Distributed load → $q = 6027.772 \left(\frac{N}{m}\right)$

Load in the supports → $\mathrm{F} = \frac{\mathrm{qL}}{2} \left(N \right) = 15069.43 \left(N \right)$

So, each support must support a load of 15.069 kN.

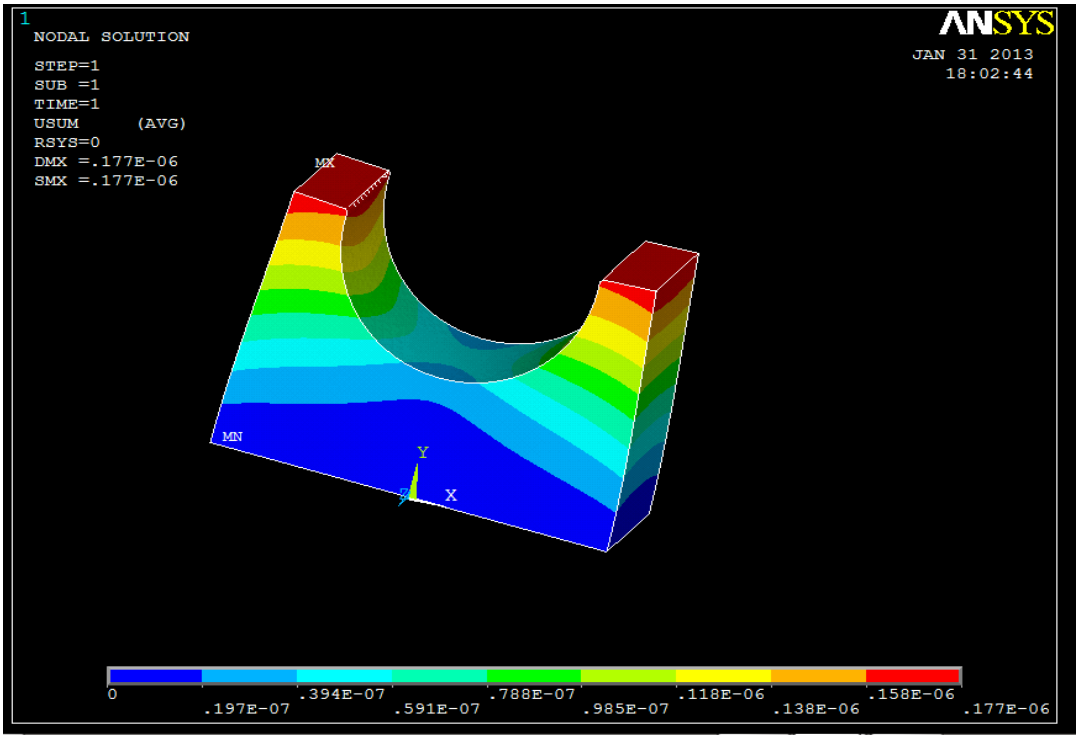
In the study of ANSYS we are going to suppose that every each support must support a distributed pressure in the hemispherical surface like this:

$$P_{supports} = \frac{F}{\pi re} = \frac{15069.43 \left(N \right)}{\pi \cdot 0.5 \cdot 0.6 \left(m^2 \right)} = 15989.1618 \left(Pa \right) = 16\ kPa$$

Taking in count a security coefficient of 3, and a adding more pressure due effects of snow and the rest of elements that will be installed in the deposit, finally we will have a pressure for the study of:

$$P_{supports} = 50\ kPa$$

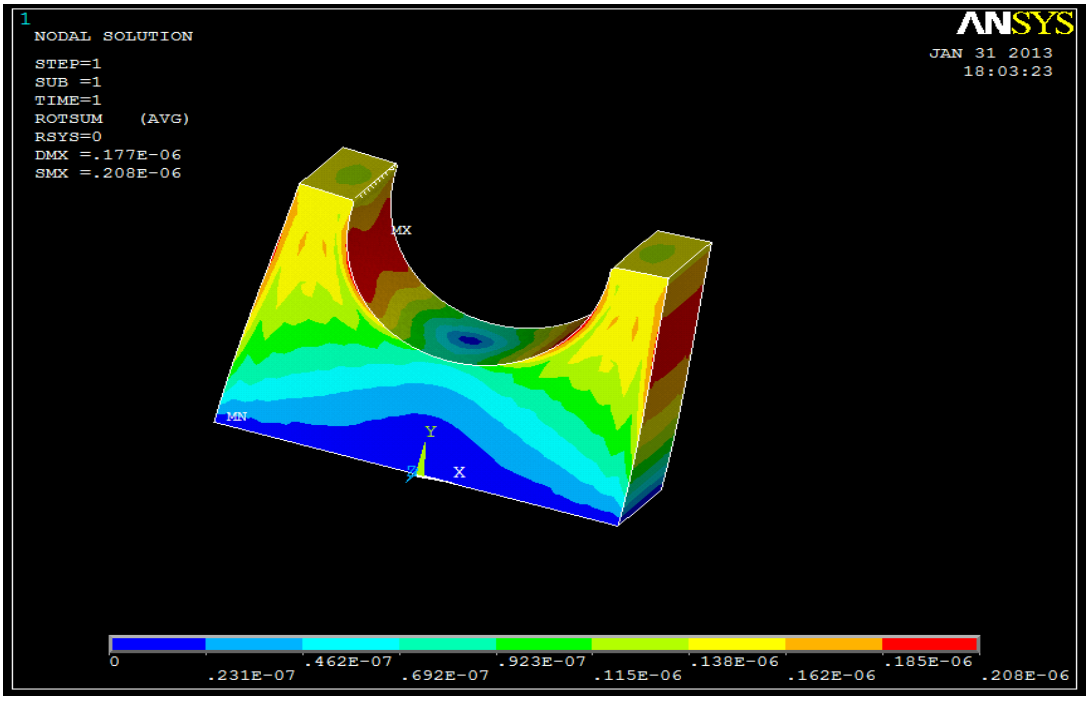
DOF SOLUTION – DISPLACEMENT VECTOR SUM



3.6 Pic 3: ANSYS analysis of the displacement in the support

In picture 3.6 Pic 3 we can see that the maximum deformation in the supports will be 0.158E-6 m, that is an insignificant deformation for the supports, so she stability of the deposit is sure.

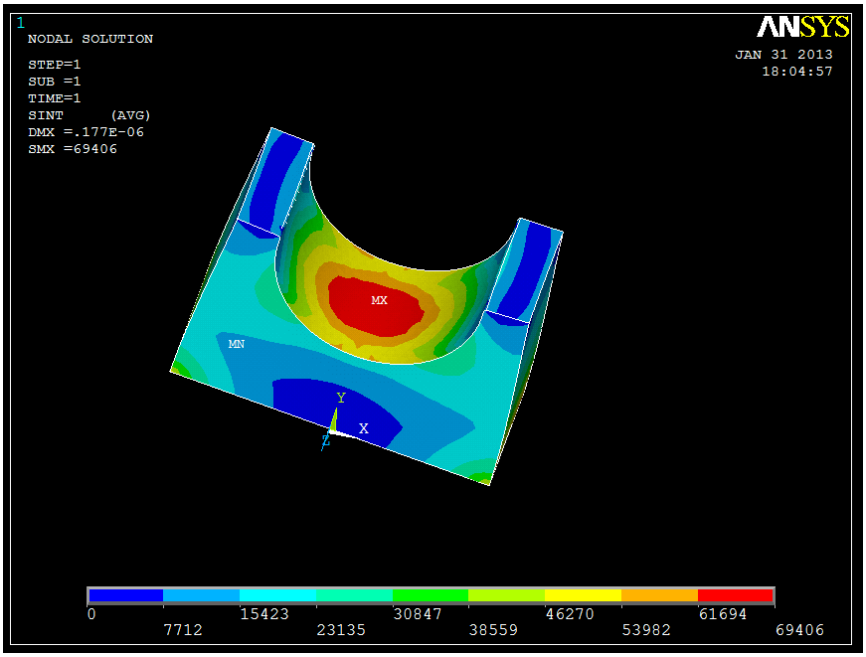
DOF SOLUTION – ROTATION VECTOR SUM



3.6 Pic 4: ANSYS analysis of the rotation in the support

In picture 3.5 Pic 4 we can see that the rotation induced in the supports is 0.186E-6 degrees, so is not a problem for the supports, and the steel can support the stresses induced that produce this rotation.

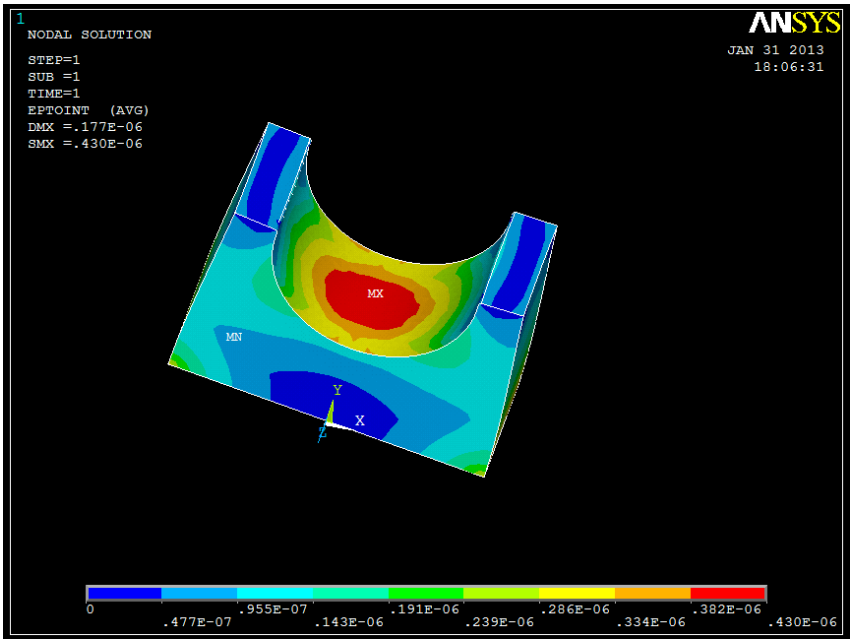
STRESS – STRESS INTENSITY



3.6 Pic 5: ANSYS analysis of the stress intensity in the support

In pic 3.6 Pic 5 we can see that the maximum point of stress is in the center of the surface where is supported the deposit, and we can see that is 62kPa approximately, stress that our support of steel can support perfectly.

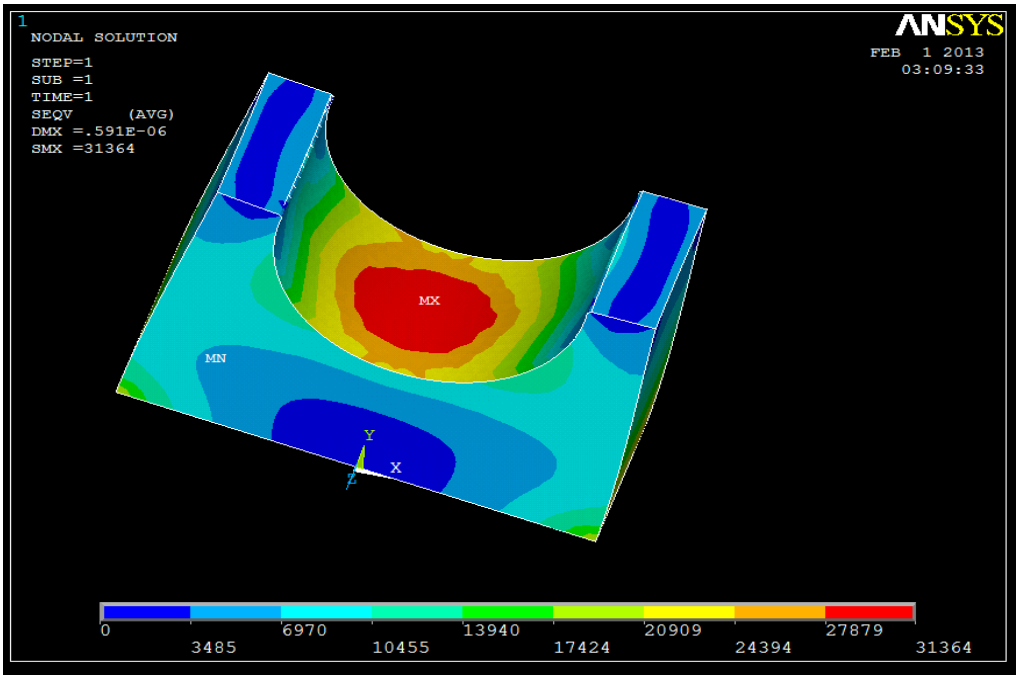
TOTAL MECHANICAL STRAIN – STRAIN INTENSITY



3.6 Pic 6: ANSYS analysis of the strain intensity in the support

In the picture 3.6 Pic 6 we can see that the point with maximum strain will have 0.382E-6 , That is equal to a deformation of 3.82E-5 % . It is an insignificant deformation.

VON MISSES ANALYSIS



3.6 Pic 7: ANSYS analysis of the Von Misses Analysis in the support

In the picture 3.6 Pic 7 we can se that making the Von Misses analysis with ANSYS with the supports we can see that the maximum point of tension have 31364 kPa, and that is not critical point for the steel.

3.7 Resume and final data of the design

Here we are going to present a schema of all necessary data of the deposit:

Parts of the deposit

1) Cylinder of 4 meters of length , 0.5 meters of external radius and 0.48 meters of internal radius made of composite
2) Two hemispherical caps , each one in the extremes of the cylinder, that have 0.5 meters of external radius and 0.48 meters of internal radius, made of composite.
3) Two supports of 140cm of width , 60 cm of ridge and 100 cm of high .Each one is established at 1 meter of the extreme of the deposit, made of Steel S275 JR .

Material of construction

The deposit is made by composite of Glass fibers and Epoxy matrix, with a 70% of fibers. The orientations of the fibers are +/- 54.74º. There is 10 sheets for each orientations, so in total we have 20 sheets and they are established like a " balanced composite " , this means that we establish them collated and symmetrical. The thickness of each sheet is 1 mm and the total thickness is 2 cm.

External elements

We use an insulator of Glass mineral wool that cover all the cylinder and hemispherical caps with a thickness of 6 mm for improve the thermal properties .

Elements used

Theory and exercise calculus combined with a program of finite elements called ANSYS.

Note

During the study and design of the deposit, also I have taken in count the Normative that is included in the references [15] and [19] about " Normative and Specifications for saving flammable and combustible fluids " .

4. Final conclusions of the project

After the design of the study we are going to make the conclusions of all the work done:

- The use of composite in the design of a deposit that must work in high pressure give us so much more qualities than with the use of the normal materials like steel or aluminum alloy like lightness combined with the strength and very good thermal properties. With a deposit of composite we can save the same quantity of combustible with less dimensions of the deposit and better properties than with a deposit of steel or aluminum alloy.

- Our deposit, with the insulator, is also designed for working in situations where the requirements can be hard, for example , working in factories where is necessary a deposit of LGP and there is high conditions of temperature. This is possible because the composite has really good thermal properties like low conductivity coefficient or very low coefficient of thermal dilatation , and this combined with the properties of the insulator, make the deposit a really useful and efficient element saving combustibles in this kind of situations of extreme temperatures.

- The use of composite make that the thickness of the deposit can be lower than the thickness of a deposit of a normal material without loosening strength or even having more. This is really useful in situations where the weight or the dimensions of the deposit is one of the most important requirements in the service, for example, in the air transport of combustibles.

- Take in count that our deposit is designed for 30 bar with a security coefficient of 3, this means that even working with higher pressures (example: 40 or 50 bar) our deposit will can support with stability and efficiency. Of course we have to take in count that this is a coefficient of security for the situations where could be an overpressure and could be dangerous for the workers or near installations, and that the official service pressure for our deposit of LGP is 21 bar.

- At first , a deposit of only with composite will be more expensive than a deposit of normal material like steel or aluminum alloy , even knowing that the thickness and the dimensions can be lower. This is because nowadays the manufacture processes for the composite and the materials are more expensive than the normal material manufacture processes. However , the combination of normal materials with the composite is making that the manufacturing of deposit are cheaper than only with normal material, obtaining better properties and dimensions without so much more expensive cost or even with less. In future the use of composite will be so much more common in specific structures like deposits.

- One of the most important skills of composite with orientated fibers as we have used in our design, is that if we need special requirements for supporting stresses or strains of specific type, we can design an specific type of composite that will support much better than the normal materials. For example the composite is widely used in aeronautic designs because of this properties.

- One of the best important conclusions of this design, is that after talk with the director of ISOLUX CORSAN S.A. (Madrid, Spain) even when we wanted to design a deposit with bigger dimensions, is more efficient, economic and save to design a small/normal deposit , and establish two or more deposits in parallel or in series. Actually is hard to find companies that manufacture this type of big deposits, so is easier and cheaper to design a deposit that has the common dimensions and find a company that manufacture it.

- Taking in count the elements used in the design, I have to mention that ANSYS is a really efficient and powerful program in the design and analysis of structures, that can give you the first idea of how is designed your structure and possible mistakes in the design. The bad point is that is too much complicated to use. There is better programs that make the same function with more facilities like CATIA, SOLID WORKS or WORKBENCH . The last is a more intuitive variant of ANSYS that has been developed the last year.

- After the realization of the modal analysis with ANSYS we have to say that is one of the most important points in the design of an structure. If our deposit is going to be established in a place where can suffer vibrations and getting the resonance frequency , it must be established a vibration control system in order to keep the security, because for a deposit of our characteristics that save LGP that with a percent or air can be combustible and flammable and that is saved at high pressure, a in this topic can be catastrophic for the structure and for the security of the people and the near buildings.

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